

JET

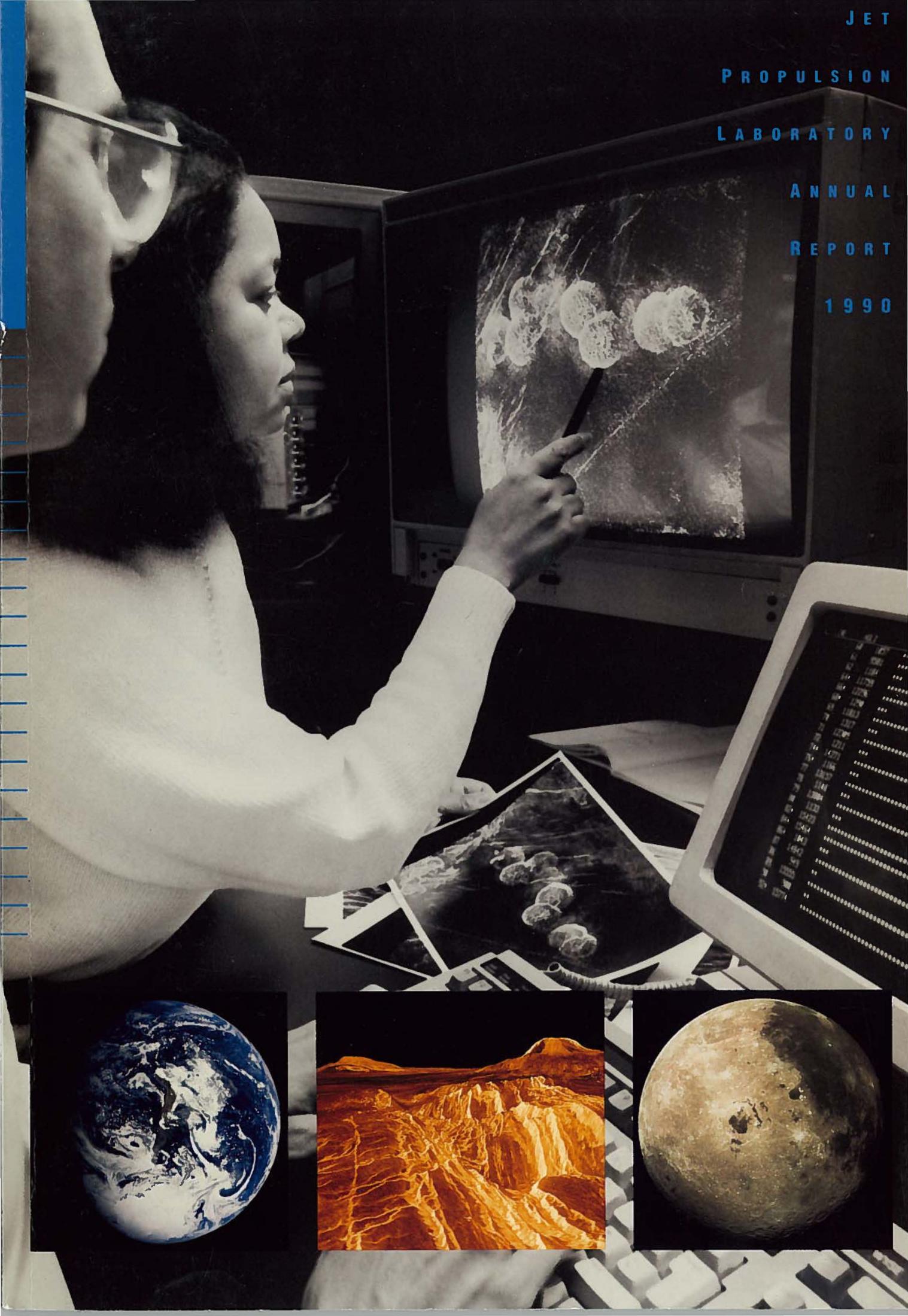
PROPELLION

LABORATORY

ANNUAL

REPORT

1990



Cover: Image analysts study the domed lava formations detected by Magellan south of Venus' equator.

Insets: (Center) This view of deep lava flows and two large Venusian volcanoes — Gula Mons on the right horizon and Sif Mons — was made from Magellan data. Images taken during Galileo's Earth flyby show (left) huge storm fronts over the Atlantic Ocean and South America and (right) the Moon's dark side revealed for the first time.

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A description of work accomplished under contract between the California Institute of Technology and the National Aeronautics and Space Administration for the period January 1 through December 31, 1990.

JET PROPULSION LABORATORY

California Institute of Technology
Pasadena, California

The Jet Propulsion Laboratory, an operating division of the California Institute of Technology (Caltech), performs research, development and related activities for the National Aeronautics and Space Administration. The people of JPL share a common objective: research and development in the national interest.

Three characteristics shape JPL's philosophy, mission and goals:

- (1) As part of Caltech, JPL pursues the highest standards of scientific and engineering achievement. Excellence, objectivity and integrity are the guiding principles.
- (2) As NASA's lead center for unmanned exploration of the solar system, JPL directs unmanned planetary missions for the United States.
- (3) JPL helps the United States solve technological problems and performs research, development and spaceflight activities for NASA and other agencies.

JPL's mission evolved from pioneering rocket research through guided-missile work to space missions. Today, JPL is a preeminent national laboratory with a budget of more than \$1 billion and a work force of more than 5,000 people. JPL's charter continues to emphasize exploration of the solar system.

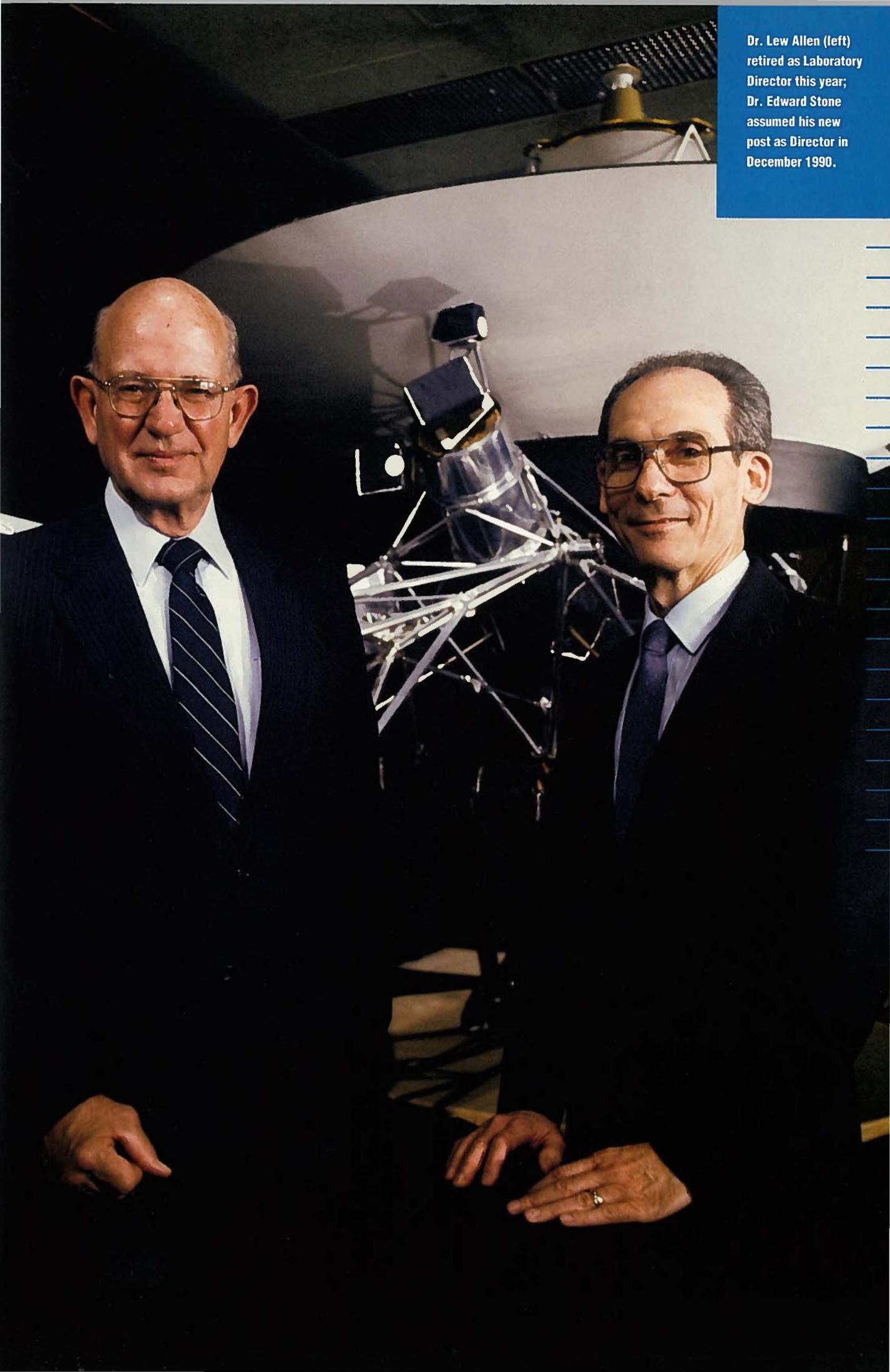
The year reported here, 1990, was characterized by success in many areas. The Galileo, Magellan, Ulysses and Voyager spacecraft all passed major milestones in their missions; the Mars Observer and TOPEX/Poseidon projects made significant progress toward their planned launch dates. The Laboratory also expanded its supercomputing capabilities and made notable advances in automation and robotics as well as microelectronics and spaceborne sensors. In short, 1990 was a very good year for the Laboratory.



Nineteen ninety was a year of exciting discoveries for the Laboratory. Voyager 1 gave us a stunning and humbling view of the solar system. The images were taken at such vast distances that the planets appear no larger than dust motes. A captivating view of the rugged terrain of Venus was returned by the Magellan radar as it peered through the thick Venusian clouds. And as Galileo passed Earth en route to Jupiter, it recorded the majestic sight of Earth and the far side of our Moon, both set against the blackness of space. Indeed, 1990 must be regarded as one of the more successful and satisfying years in the history of the Jet Propulsion Laboratory (JPL) and the National Aeronautics and Space Administration (NASA).

JPL's flight projects — Voyager, Magellan, Galileo and Ulysses — all performed well in space flights, raising the tempo of space operations at JPL. Other flight projects — TOPEX/Poseidon, Mars Observer and CRAF/Cassini — made significant progress toward their future launch dates. Also gratifying was the progress made in the development of the Wide Field/Planetary Camera 2, which is being modified to compensate for the flaw in the Hubble Space Telescope. The Synthetic Aperture Radars (SARs) are major elements of a growing Earth science program at JPL. SARs and a number of other instruments are being developed for NASA's Earth Observing System. Several command and control systems developed for the U.S. military by JPL proved to be very useful during the Persian Gulf operation.

Dr. Lew Allen (left) retired as Laboratory Director this year; Dr. Edward Stone assumed his new post as Director in December 1990.



In other areas — supercomputing, micro-electronics, tracking and information handling — the work of JPL engineers and scientists was recognized to be at the forefront of world technology.

This year marked the retirement of two Laboratory executives, Associate Director Dr. C. R. (Johnny) Gates and General Counsel Dr. Donald Fowler. Dr. Gates retired after 40 years of service, Dr. Fowler after 25 years.

This was also my final year as Director of the Laboratory. I have greatly enjoyed my eight years at JPL, having participated in a wide range of exciting science and engineering projects and having interacted with as fine a

group of men and women as I have ever known.

I am delighted that the Board of Trustees has selected Dr. Edward C. Stone as the new Director and as a Vice President of the California Institute of Technology. Dr. Stone has a distinguished record as a scientist and manager and has proven ability to lead JPL in meeting the great opportunities and challenges of the coming decade.

The Jet Propulsion Laboratory is a world-renown center of scientific and technical excellence. I am confident that it will continue to be so because of the dedication and creativity of its people.

This was another gratifying year for JPL's flight project teams and planetary scientists as they began amassing a wealth of scientific data from two spacecraft, Magellan and Galileo, both launched in 1989. After completing its cruise to Venus, Magellan was accurately inserted into a near-polar orbit in August 1990, and mapping of the Venusian surface began one month later.

Magellan's spectacular radar imagery has thrilled science investigators. These early returns are settling some scientific disputes and sparking new ones. Galileo, still in the early days of its six-year journey to Jupiter, has returned fascinating images of Earth, the Moon and Venus' dynamic cloud cover, all taken as the spacecraft picked up gravity assists from the two planets. The two spacecraft are obtaining complementary data of Venus; Magellan's radar sensor penetrates the planet's thick clouds, and Galileo's sensors image them.

Early in the year, the venerable Voyager project surprised us once again with spectacular images of six of the nine planets in the solar system. And in October, Ulysses was launched on its mission to explore the Sun's poles and peer into interstellar space.

Four more projects were being readied for missions scheduled later in the decade. The Ocean Topography Experiment (TOPEX)/Poseidon satellite will be completed in 1991 and launched on Ariane the subsequent year. Mars Observer will be launched in 1992 aboard a Titan III, resuming JPL's exploration of the Red Planet. The Laboratory's most recent project, the joint Comet Rendezvous Asteroid Flyby (CRAF) and

Cassini missions, is scheduled for launch in the mid-1990s. Cassini will travel to Saturn, where it will sample the atmosphere of its moon Titan and dispatch a probe to Titan's surface. The CRAF mission — a rendezvous with a comet after flying by an asteroid — will follow.

JPL's ongoing flight projects and new programs present exciting challenges in deep space exploration for the remainder of the decade.

MAGELLAN

Planetary scientists were ecstatic over the abundance and quality of Venusian images returned by the Magellan spacecraft as it began mapping the surface of the planet on September 15. Vast areas of volcanic lava flows, faults, rift valleys and mountains are revealed in sharp detail by Magellan's crisp radar images. Also clearly visible are impact craters, evidence of windblown material, volcanic domes and calderas and other geologic features.

The Magellan spacecraft, launched aboard the Space Shuttle Atlantis on May 4, 1989, was successfully inserted into a near-polar orbit around Venus on August 10, after completing a 15-month cruise. Mapping operations were delayed about two weeks because of problems that appeared during in-orbit checkout. The spacecraft's attitude control computer was sometimes unable to access a portion of its memory, causing a

temporary communication loss. As a result, the spacecraft was put into a self-protecting mode, and normal attitude control was soon restored. The spacecraft's computer also had to be restarted several times after intermittent outages. Fortunately, these problems are not jeopardizing the overall success of this exciting project.

As Magellan prepared for the first mapping cycle, some data-gathering opportunities were missed because of a delay in mapping operations and the two-week hiatus in October during the solar conjunction (when Venus and Magellan were on the far side of the Sun as viewed from Earth). Once the mapping operations began, however, the spacecraft settled into a routine of eight daily orbits. The radar system has performed almost flawlessly, and mapping operations will continue during Venus' 243-day rotation.

Magellan's radar data pour in at the unusually high rate of 268.8 kilobits per second for two hours of each three-hour orbit. At this record pace, Magellan will return more data by March 1991 than all previous planetary missions combined. The data are processed at the Space Flight Operations Facility where engineering information is extracted from the radar image data. An experimental data record is produced and subsequently processed in the Synthetic Aperture Radar Data Processing System. This system creates an image strip showing an area 16,093 kilometers (10,000 miles) long by 26 kilometers (16 miles) wide. Each orbit produces one such strip. The strips are then either combined to create mosaics or separated into individual sections to highlight specific areas for science investigators.

The spacecraft's Synthetic Aperture Radar is able to distinguish features as small as 150 meters (492 feet) across — an order of magnitude better than the 1.2- to 2.4-kilometer (0.7- to 1-mile) resolution of the images from the Soviet Venera 15 and 16 obtained 7 years ago and two to three orders of magnitude better than the Pioneer images of Venus obtained 12 years ago.

Scientists will be poring over a wealth of Magellan data for years to come. Early examinations of the imagery confirmed many expectations and offered some startling surprises. The images reveal a tortured planetary surface with evidence of geological formations familiar on Earth — volcanism, impact cratering and compressional and extensional deformations of the surface. The variety of volcanic features is extensive. There are narrow riverbeds — hundreds of kilometers in length — probably formed by very fluid, swiftly moving lava. Also shown is an unusual series of six flat, symmetrical, pancake-shaped domes, approximately 20 kilometers (12 miles) across and about 1 kilometer (0.6 mile) high. Some domes overlap one another, indicating a volcanic progression.

The imagery also reveals large, almost featureless plains of lava — thousands of kilometers across and thousands of meters deep — and high mountain ranges originally formed by compression and covered by troughs indicating volcanism. These mountains appear to be experiencing extensional deformation as they tear themselves apart. They are so hot and the atmospheric pressure so great that planetary gravity is causing them to subside.

The planet also has some intriguing crater formations. Venus' impact craters appear to be newly formed, suggesting that the planet's surface is not active except in cratered areas. Outflow channels appear beneath some craters, indicating that cratering may have triggered lava flows. A small percentage of the craters have dark "halos" around them, an unusual feature. These halos appear to be finely grained soil, possibly created by meteoric impact that pulverized the surface soil, which was then compressed by the Venusian atmosphere. Based on observations of crater density and other data, scientists now date the age of the planet's surface at 400 million years.

Magellan's images show no evidence of small craters, supporting previous speculation that small projectiles burn up in Venus' atmosphere before impact. The smallest impact craters detected have irregular-shaped rims, indicating they have been formed by objects that had broken apart during descent. The imagery also reveals a variety of crater formations: some are kidney-bean shaped, others exhibit asymmetric ejecta patterns and still others are imprinted with what appear to be multiple depressions.

The radar imagery does show evidence of deposits or streaks from eolian (wind-related) activity. Although scientists expected to see evidence of strong wind activity, they did not expect to discover the fine particles resulting from either erosion or impact cratering. They were also surprised by the long linear features on the surface, which suggest the crust of the planet has experienced extensive tectonic activity.

The variety of terrain formations seen in Magellan's imagery will help scientists understand the processes that formed this intriguing landscape and possibly, by comparison, will shed light on our own planet's evolutionary process.

GALILEO

During the year, Galileo completed two of the three critical milestones on its long trip to Jupiter — gravity-assist flybys of Venus and Earth. The spacecraft, launched by the Space Shuttle Atlantis on October 18, 1989, will conduct pioneering in-depth investigations of Jupiter starting in 1995. Galileo will make the first direct measurements of the planet's gaseous atmosphere and will conduct the first lengthy observations of Jupiter, including its magnetosphere and satellites. The Galileo mission could be the most stunning and scientifically rewarding planetary mission of the decade.

On February 10, as Galileo passed Venus traveling at an altitude of 16,123 kilometers (10,018 miles), a perfect gravity-assist operation was conducted. This operation and two subsequent gravity assists from Earth will provide the additional energy the spacecraft needs to reach its planetary objective. In preparation for the second gravity assist that occurred on December 8, a series of six correction maneuvers was performed to refine the trajectory so the spacecraft passed 960 kilometers (596 miles) above the Earth's surface.

Galileo will make the first spacecraft encounter with an asteroid when it flies within a thousand kilometers of the small asteroid Gaspra in October 1991. During the flyby, the project team will activate the spacecraft's fields and particles experiments. Galileo will then orbit the Sun one more time, flying by Earth in December 1992 for its third and final gravity assist before coasting to Jupiter.

The Venus and Earth flybys yielded significant scientific data. Galileo's instruments obtained both near-infrared and high-resolution images of Venus, Earth and the Moon. Because the spacecraft's high-gain antenna remains furled until later in the mission, data from Venus were stored aboard Galileo and transmitted through a low-gain antenna to Earth in November 1990.

Galileo's vivid images of Venus' clouds, taken at flyby ranges of approximately 1.6 to 3.2 million kilometers (1 to 2 million miles), revealed cloud features 20 miles or larger. At certain wavelengths, the imaging system was able to observe the movement of lower clouds. Galileo's near-infrared mapping spectrometer also provided a detailed look at the dark side of Venus, and a magnetometer monitored interactions of the solar wind with the planet.

During the first Earth flyby, Galileo captured spectacular views of both the dark and sunlit sides of our planet. The observations spanned seven days, starting on December 8 as the spacecraft made its closest approach to Earth. Galileo took color images of our planet every six minutes for 24 hours while looking back at the receding planet. The imagery provided a color movie of a rotating, sunlit Earth. The spacecraft also captured images of the Moon, including views of its dark side not visible from Earth.

These notable accomplishments are a dress rehearsal for Galileo's 1995 dramatic encounter. At that time, a probe will separate from the main spacecraft and enter the Jovian atmosphere. The orbiter portion of Galileo will be directed into an ever-changing orbit around Jupiter, making a series of encounters with the planet's major satellites.

The Galileo orbiter was built by JPL and the atmospheric entry probe by NASA's Ames Research Center. The probe will be deployed 150 days before the spacecraft arrives at Jupiter.

As the probe descends through Jupiter's atmosphere, it will send data to the orbiter for relay to Earth. The probe carries 6 instruments, the orbiter 11. These instruments will be used to study Jupiter's atmosphere, its magnetosphere and its satellites.

ULYSSES

Ulysses is a cooperative mission between NASA and the European Space Agency (ESA) to study the Sun's poles and interstellar space near the polar regions. Ulysses

was launched on the Space Shuttle Discovery on October 6, 1990. The spacecraft, along with its Inertial Upper Stage/Payload Assist Module boosters, was deployed from the cargo bay of the shuttle about six hours after liftoff. Approximately one hour later, a series of three upper-stage burns sent Ulysses speeding toward Jupiter, faster than any human-made object ever to leave Earth.

As Ulysses headed toward Jupiter, the spacecraft's instruments were checked and found to be performing satisfactorily. A nutation (wobbling motion) of approximately six degrees about the spacecraft's spin axis occurred in November. Project scientists believed the nutation would subside when sunlight on the axial boom decreased, lessening solar heating of the boom. This prediction proved correct. As the spacecraft traveled farther from the Sun, the nutation decreased and by mid-December was reduced to zero degrees.

In 1992, Ulysses will fly by Jupiter for a gravity assist that will provide the acceleration needed to orbit the Sun's south pole during the summer of 1994 and the Sun's north pole a year later. During its two-week Jupiter flyby, Ulysses will attempt to measure the Jovian magnetosphere and search for gravitational waves.

JPL has multiple roles in the joint NASA-ESA project. The Laboratory is responsible to NASA for mission design and the interface between the shuttle and the spacecraft. In addition, JPL has tracking and data acquisition responsibility, manages the U.S.-funded experiments and shares the navigation role with ESA.

VOYAGER

On February 14, Voyager 1 made history once again — snapping a family portrait of six of the nine planets in the solar system. Positioned approximately 40 astronomical units (3.7 billion miles) from Earth and using a wide-angle camera with a clear filter, Voyager obtained 39 images, starting with Neptune and proceeding inward toward the Sun. Three narrow-angle images were taken of each planet using blue, violet and green filters. The data were then transmitted back to Earth, where the color images were reconstituted at the Laboratory. In these historic images, Neptune, Uranus, Saturn, Jupiter, Earth, Venus and the Sun are clearly visible. Mercury and Pluto, however, are not shown — Mercury because it was shadowed by the Sun, and Pluto because it was too dark, too small and too far away. Also Mars was not identifiable in the images because of its small size and the poor phase angle at the time it was imaged.

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Since their tandem launches in late summer 1977, the two Voyagers have taken approximately 67,000 images during 12 1/2 years of travel. The family portrait of six of the planets — collected in 60 frames, 39 wide angle and 21 narrow angle — is a triumphal finale to the illustrious Voyager Project.

During the year, the project team modified ground software to streamline the sequencing process and the stored-block routines on the spacecraft. These modifications reduce the number of commands that must be transmitted to the spacecraft, thereby making it possible to fly the spacecraft using a smaller team.

Voyager 1 explored its last planet, Saturn, a decade ago and is exiting the solar system at approximately 520 million kilometers (320 million miles) a year, some 35 degrees above the ecliptic plane. Voyager 2 travels about 470 million kilometers (290 million miles) a year, 48 degrees below the ecliptic. Both spacecraft continue to sample the interplanetary medium, conduct ultraviolet stellar astronomy and search for the heliopause, where the influence of the Sun's magnetic field ends.

Before reaching the heliopause, the two spacecraft are expected to pass a termination shock wave, where the solar wind slows abruptly from supersonic to subsonic speeds. The Voyagers may pass the shock wave in the next 5 to 20 years. If both spacecraft stay healthy, the flight team expects them to operate for another 25 to 30 years, after which their electrical power should drop too low to operate the science instruments.

MARS OBSERVER

The Mars Observer is scheduled for launch in September 1992. A Titan III launch vehicle will deliver the spacecraft to Earth orbit where a Transfer Orbit Stage will boost it toward Mars. After an 11-month cruise, Mars Observer will begin mapping the Red Planet, generating data on the planet's atmospheric composition and density as well as its gravitational and surface characteristics. These data could significantly influence our future robotic and manned missions to Mars.

This mission resumes our exploration of Mars initiated by JPL's Mariner 4 in 1965. It also takes on national significance in light of the investigations aimed at human exploration. Among the studies planned are in-depth global investigations of the Martian atmosphere and dust particles within the atmosphere conducted during the planet's four seasons. Previous atmospheric investigations by Mariner 9 and Viking were limited in scope and duration. Mars Observer, however, will obtain images that are 10 to 50 times sharper than Viking's.

During the year, final design reviews were held and software requirements were finalized. Project personnel began fabricating flight assemblies for both the spacecraft and its instruments. Early in 1991, the spacecraft bus will enter final assembly and testing. Instruments scheduled for mid-year delivery will be integrated with the bus and tested, starting in June 1991. By year's end, the spacecraft will be environmentally tested.

In December 1993, Mars Observer will begin mapping the planet's surface. The mapping mission will span 687 Earth days — equivalent to one Martian year. Near the end of the mapping mission, in late 1995, the spacecraft may serve as a backup for the Soviet spacecraft Mars '94 balloon experiments. The Soviet balloons will be released into the Martian atmosphere, and data from the balloons will be radioed to Mars Observer. The data will be formatted on board the spacecraft using equipment supplied by the French Space Agency (Centre Nationale d'Etudes Spatiales) then transmitted to Earth. This activity is part of a Franco-Soviet Balloon Relay Experiment.

NASA and JPL have a cooperative arrangement with the Soviet Union on science experiments for the mission. JPL is responsible for project management, mission design and mission operations of Mars Observer. General Electric's Astro-Space Division is building the spacecraft.

The Comet Rendezvous Asteroid Flyby (CRAF)/Cassini program has begun development of advanced technologies for flight systems and refinement of the Mariner Mark II, a new spacecraft design being used for the two missions.

Because of delays in science payload selection and changes in Congressional funding, JPL was obliged to examine alternatives for the program. The August 1995 CRAF launch aboard the Titan IV/Centaur booster may be delayed until 1996. In that event, CRAF would rendezvous with Comet Tempel 2 in 2002, rather than with Comet Kopff two years earlier, as originally planned. The spacecraft would still fly by an asteroid — either Gelria or Hammonia — on its journey to Comet Tempel 2. Also under study is a Venus-Earth-Earth gravity-assist maneuver that would accommodate the later launch date and additional spacecraft mass.

The Laboratory is exploring a number of Cassini launch scenarios. Among them are 10 possible trajectories — all would accommodate the revised mission timetable and the Mariner Mark II spacecraft required for the Saturn orbiter/Titan probe mission. The earliest potential launch date for Cassini is November 1995, which — if decided upon — would reverse the launch sequence for the two spacecraft. Cassini would follow a trajectory that would send it

past an asteroid and both Earth and Jupiter before arriving at Saturn. At Saturn, the probe will impact Titan, the ringed planet's largest moon, while the orbiter will continue to make flybys of the planet, Titan and other Saturnian satellites.

In November, NASA announced a tentative selection of 12 instruments for the Cassini Saturn orbiter. Two months earlier, the European Space Agency — NASA's partner in the program — selected seven instruments for the Titan atmospheric probe, called Huygens for the Dutch astronomer who discovered Titan. Late in November, the French aerospace company Aerospatiale was chosen to build the ESA-funded probe.

Both the German Space Agency (Deutsche Agentur für Raumfahrtangelegenheiten) and the Italian Space Agency (Agenzia Spaziale Italiana) are active participants in the CRAF/Cassini program. Germany is providing much of CRAF's propulsion module as well as the Cometary Matter Analyzer, an instrument that will analyze the gases captured during the rendezvous. Under a bilateral partnership negotiated with NASA, the Italian Space Agency is providing most of the spacecraft's high-gain antenna, portions of the S-band and Ka-band communications equipment and the Sun sensors used for pointing the Ka-band antennas; they will also be responsible for part of the radio-science investigations for both spacecraft.

JPL will retain X-band command capability for the spacecraft but will also carry the higher frequency Ka-band equipment as an experiment. By the time Cassini reaches Saturn, the Deep Space Network will have the capability to operate at the higher frequency band to realize the advantages of greater data capacity and reduced transmission power.

TOPEX/POSEIDON

TOPEX/Poseidon, the collaborative effort between NASA and the French Space Agency (Centre Nationale d'Etudes Spatiales) to study the world's oceans, made important strides toward its goal of a mid-1992 launch aboard the Ariane. TOPEX/Poseidon will measure sea levels, map basin-wide variations in currents and monitor the effects of currents, such as the Gulf Stream, on global climatic change.

During the year, the solid-state altimeter and Doppler receiving-locating system were integrated and delivered to the spacecraft manufacturer, Fairchild Space Company. There, all sensors completed environmental testing. Flight software was completed, and near year's end, satellite and sensor readiness reviews were concluded. Much of the satellite hardware was fabricated and environmentally tested as well. In 1991, the remaining hardware should be completed and fully integrated in the spacecraft for testing.

TOPEX/Poseidon — scheduled for launch from ESA's space center located in Kourou, French Guiana — will be lofted into a 66-degree inclined Earth orbit at an altitude of 1,336 kilometers (830 miles). It will use NASA's Tracking and Data Relay Satellite System for command operations and data acquisition.

From orbit, TOPEX/Poseidon will study oceanic circulation patterns; its radar altimeters — supplied by France and the United States — will map the contours of sea floors. A laser retroreflector will permit orbital tracking, and a microwave radiometer will correct for atmospheric effects.

Thirty-eight principal investigators have been chosen to study data returned by TOPEX/Poseidon. Their findings will help us assess global change and improve our weather forecasting and pollution control. These data will also help us evaluate the health of offshore and coastal areas throughout the world.

FUTURE MISSIONS

The Laboratory is studying a number of future missions that would focus on four principal areas: astrophysics, planetary science, Earth science and space physics.

In astrophysics, NASA selected JPL as the lead center for the proposed Space Infrared Telescope Facility (SIRTF). This cryogenically cooled observatory would conduct infrared astronomical investigations from an orbit 100,000 kilometers (62,000 miles) above the Earth's surface and would be the last of NASA's quartet of Great Observatories. SIRTF would follow the Hubble Space Telescope, the Gamma Ray Observatory and the Advanced X-Ray Astronomical Facility — each one exploring separate spectral regions. SIRTF's location in space, its several thousandfold increase in sensitivity over previous orbiting telescopes and its anticipated orbital lifetime of five years give this infrared observatory an unparalleled ability to observe cosmic birth and evolution.

A second astrophysics study under consideration is a submillimeter imaging and line survey (SMILS) mission. From Earth orbit, the SMILS spacecraft would conduct physical and chemical studies of high red-shifted galaxies, molecular clouds and star-forming regions. The spacecraft would also study planetary atmospheres and surfaces.

In planetary studies, the Laboratory is examining a lunar observer mission to further study the Moon's resources. Also being considered are a number of solar system exploration missions, including a Mars environmental survey, a comet nucleus sample return and a Neptune orbiter/probe and Pluto flyby. The Laboratory is also supporting a NASA effort called Toward Other Planetary Systems, a program that would research various techniques for detecting extrasolar planets around nearby stars.

To support these future studies, JPL analysts are assessing the utility of small, relatively inexpensive spacecraft. As part of a program called Discovery, analysts are trying to determine whether successful missions can be accomplished with small spacecraft of necessarily limited capability. The kinds of missions envisioned include a near-Earth asteroid flyby/rendezvous and a lunar aeronomy project.

In Earth science, JPL is studying a polar-orbiting synthetic aperture radar capable of operating with other instruments on NASA's Earth Observing System. The Laboratory is also considering a topographic mapping mission that would acquire imaging data of the Earth's land and ice areas.

Also being considered is a solar probe mission in which a heat-shielded spacecraft will fly within four solar radii of the Sun's center as part of a near-term deep space physics study. The Laboratory is also assessing several other studies including a Mercury dual orbiter, an interstellar probe and a global solar network and monitor.

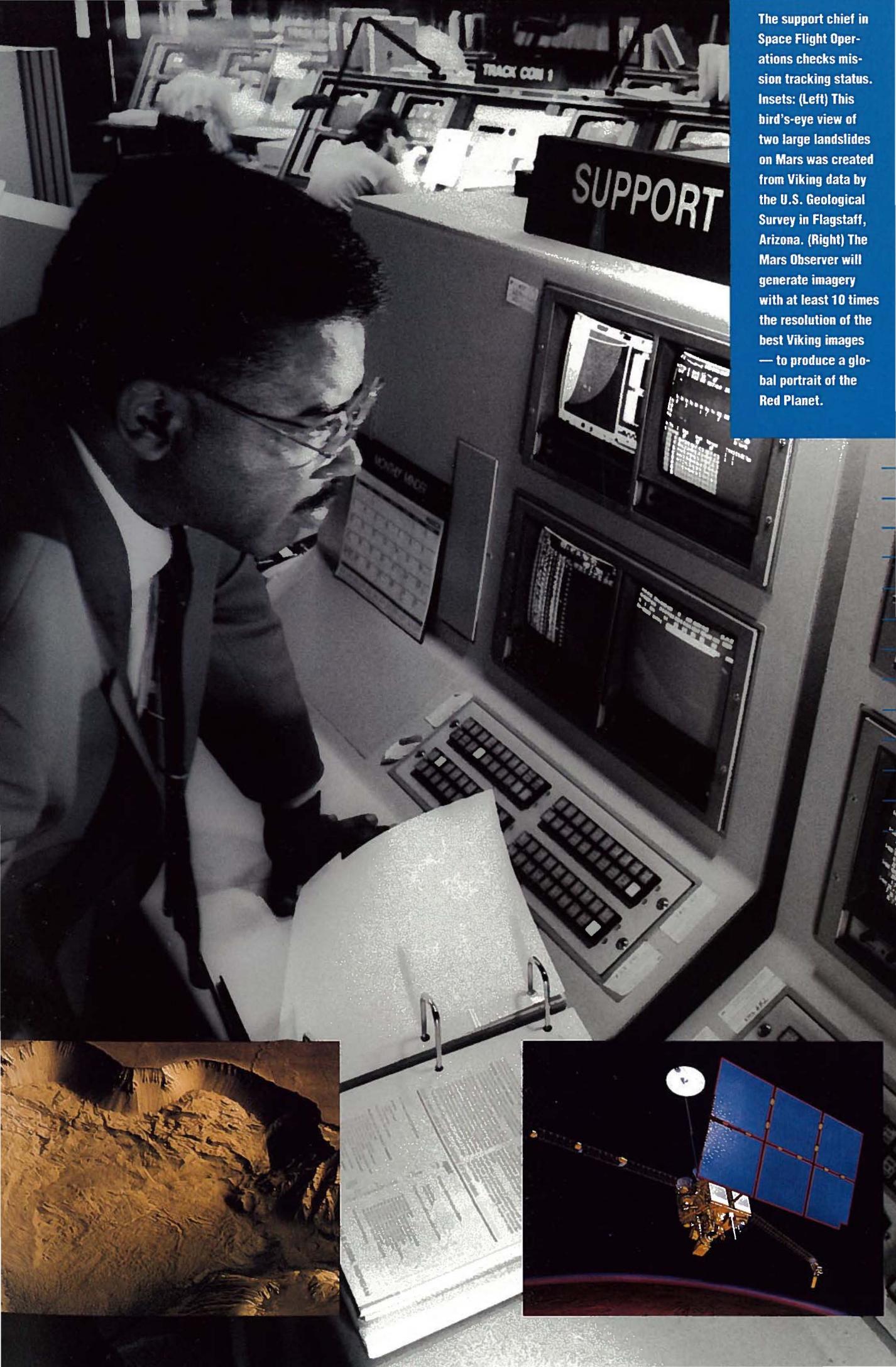
FLIGHT PROJECTS SUPPORT

The Flight Projects Support Office's success in handling the Galileo Venus and Earth flybys, the Magellan-Venus orbit insertion and the launch of Ulysses once again demonstrated JPL's expert capabilities in operations and control and logistical support for multiple missions. This office provided ground data systems, mission support facilities and physical and data systems security for continuous and complete support.

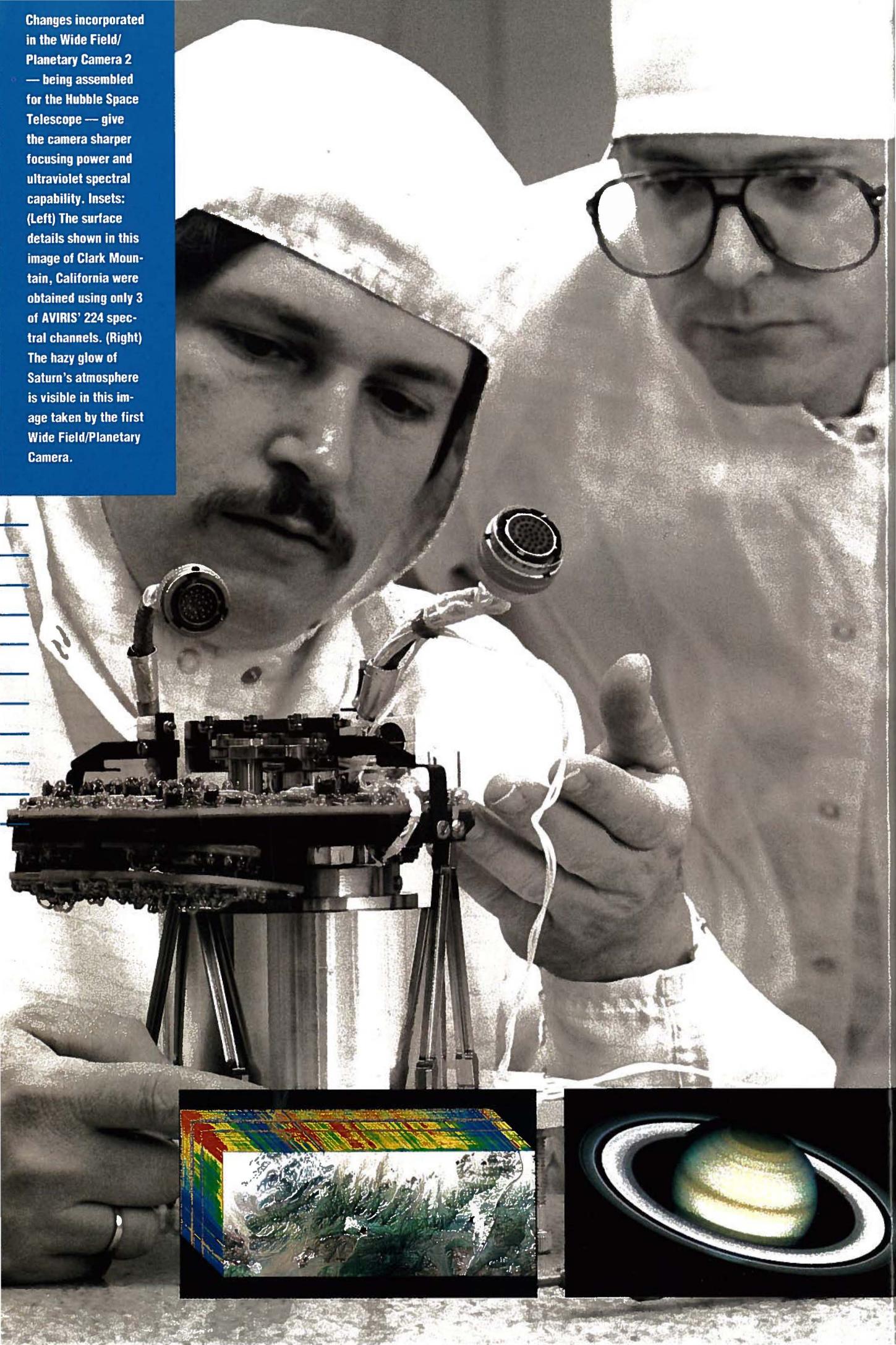
JPL's multimission concept is being expanded to encompass activities previously performed on a single-project basis. Four projects — Magellan, Galileo, Ulysses and Voyager — are supported by the multi-mission control team at the Space Flight Operations Facility. In the future, 8 or 10 simultaneous missions are expected. The Laboratory, similarly, is applying techniques for allocating the resources of the Deep Space Network among many competing spacecraft programs.

In 1989, a study to identify those technologies with the greatest potential for improved efficiency and reduced operations costs was initiated. Significant accomplishments included the definition of a spacecraft analysis system that could monitor the health and safety of a number of spacecraft.

The support chief in Space Flight Operations checks mission tracking status. Insets: (Left) This bird's-eye view of two large landslides on Mars was created from Viking data by the U.S. Geological Survey in Flagstaff, Arizona. (Right) The Mars Observer will generate imagery with at least 10 times the resolution of the best Viking images — to produce a global portrait of the Red Planet.



**Changes incorporated
in the Wide Field/
Planetary Camera 2**
— being assembled
for the Hubble Space
Telescope — give
the camera sharper
focusing power and
ultraviolet spectral
capability. Insets:
(Left) The surface
details shown in this
image of Clark Moun-
tain, California were
obtained using only 3
of AVIRIS' 224 spec-
tral channels. (Right)
The hazy glow of
Saturn's atmosphere
is visible in this im-
age taken by the first
Wide Field/Planetary
Camera.



Much of the Laboratory's work in space and Earth sciences furthers our understanding of the evolution and geology of the planets, the phenomena of interstellar space and the global processes at work here on Earth. Research in these areas has also generated a host of new instruments providing improved measurements of both space and Earth environments. This year's work, in particular, gave us new insights into the environments of Earth and Venus and the far regions of interstellar space.

EARTH SCIENCE

Airborne Visible/Infrared Imaging Spectrometer

Flying 20 kilometers (12 miles) above the Earth's surface in NASA's high-altitude ER-2 research aircraft, the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) is acquiring data of unsurpassed quality on Earth's environment. AVIRIS is the first fully calibrated imaging spectrometer with a spectral range that covers the visible to near-infrared, acquiring images in 224 narrow spectral bands or colors.

The data collected during AVIRIS' initial operational flight are being used in many areas of Earth science research. The spectrometer's spatial and spectral characteristics allow high-resolution mapping of the total atmospheric water vapor content. These data are useful for modeling the hydrological cycle and for determining relative slopes and elevations (elevation influences total water vapor content in a column of air).

In terrestrial ecology, AVIRIS' infrared measurements are being used to study forest biochemistry in both temperate and tropical ecosystems. These data help researchers trace biochemicals such as carbon — a gas that contributes to greenhouse warming — in forested areas.

AVIRIS has also provided biological oceanographers with the first images of phytoplankton patchiness in the open sea.

These patches are key reservoirs of carbon and other important biochemicals. Researchers are using these observations to study the biology of inland lakes and to determine the water content and chemistry of snow. In geology, AVIRIS' high spectral resolution has made it possible to identify many important rock-forming minerals.

Future research using AVIRIS will allow scientists to conduct global studies using spaceborne rather than airborne imaging spectrometers. Two such instruments, the High-Resolution Imaging Spectrometer and the Moderate-Resolution Imaging Spectrometer, will be used for NASA's Earth Observing System.

Upper Atmosphere Balloon Campaign

During the year, JPL conducted several balloon-borne gondola flights to study the composition of Earth's upper atmosphere. These gondolas, each measuring 1.8 meters square by 3 meters high (6 feet square by 10 feet high) and weighing 3,000 pounds, carried several scientific instruments to measure substances in the stratosphere. Measurements were taken at altitudes of 39.6 kilometers (24.6 miles), providing data on ozone levels in the upper atmosphere. The data gathered from the balloon experiments should reveal the effects of deforestation and fossil fuel pollution on ozone levels.

The gondolas, launched from the National Scientific Balloon Facility at Fort Sumner, New Mexico, used plastic balloons having a volume of 7 million cubic meters (28 million cubic feet), 50 times the size of the Goodyear blimp. Instruments carried on the gondolas measured a variety of compounds: the Microwave Limb Sounder detected chlorine monoxide and ozone; the far-infrared instrument searched for hydroxide; an ultraviolet photometer detected ozone, and the Smithsonian Astrophysical Observatory far-infrared spectrometer investigated trace compounds. In another flight, the far-infrared instrument and the ultraviolet photometer were augmented by JPL's Mark IV infrared spectrometer, which had flown in NASA's DC-8 during Antarctic and Arctic aircraft campaigns.

Atmospheric Trace Molecule Spectroscopy Experiment

Late in the year, Laboratory science and project teams were readying the Atmospheric Trace Molecule Spectroscopy (ATMOS) Experiment for an upcoming flight aboard the Space Shuttle Columbia. The ATMOS experiment measures the abundance of minor and trace molecular constituents in Earth's atmosphere and profiles their vertical distributions at altitudes between 10 and 150 kilometers (6 and 93 miles).

Data collected during ATMOS' first flight on Spacelab 3 in 1985 were published in the last of a series of atlases showing the high-resolution infrared spectra of Earth's atmosphere and the Sun's photosphere. The data were obtained at a spectral range of 2 to 16 microns. The ATMOS Solar Atlas also contains the first observations of the Sun's infrared spectrum made from outside Earth's atmosphere.

In collaboration with researchers at the University of Liege and Royal Observatory in Belgium, JPL scientists are looking at ways of using ATMOS observations to measure elemental and molecular abundances in the solar photosphere. They also will study the dynamic and convective processes in the Sun's atmosphere.

During Columbia's long standdown after the Challenger accident, ATMOS generated a data base of observations made from JPL's Table Mountain Observatory. The data, which span five years, are being analyzed for naturally occurring trends in atmospheric composition and the effects of synthetic chemicals.

Shuttle Imaging Radar

The latest version of JPL's Shuttle Imaging Radar, SIR-C, will be flown on three future shuttle missions. The SIR-C will be accompanied by another Synthetic Aperture Radar, SAR-X, which will operate in a different frequency band. The SAR-X is being developed jointly by German and Italian companies. Both radars will pioneer a number of global scientific studies, simultaneously providing the first spaceborne multifrequency radar imaging of Earth. The SIR-C and SAR-X are the first spaceborne high-resolution imaging radars with multi-polarization capability and a high-efficiency distributed antenna array.

These radars will be flown aboard the Space Radar Laboratory missions, which will serve as a SAR testbed where radar sensors and SAR-related technology will be evaluated for applicability to the Earth Observing System's free-flying polar platforms. An ocean wave data processor, developed at Johns Hopkins

Applied Physics Laboratory, is one of the instruments that will be tested by the Space Radar Laboratory. The processor will be used to demonstrate how a low-altitude SAR performs global wave forecasts using real-time estimates of the directional ocean wave spectra. The data will be relayed to Earth through NASA's Tracking and Data Relay Satellite System and will then be processed in near-real time at NASA's SAR Processor Facility located at JPL.

The Space Radar Laboratory's special sensitivity combined with its range-of-viewing parameters and all-weather capability will assist researchers in a variety of Earth science investigations — in geology, ecology and plant science, hydrology, oceanography and glaciology.

SIR-C's power, redundancy and scanning requirements are similar to those of the SAR that will be used for the Earth Observing System. The SIR-C is designed to provide the optimum wavelengths, polarizations and illumination geometries for spaceborne imagery of Earth. JPL's SIR-C instrument will collect data in L-band (23-centimeter wavelengths) and C-band (6-centimeter wavelengths) through a range of selectable angles of incidence and in four polarization states. The European SAR-X radar will gather data in X-band (3-centimeter wavelengths) with one polarization.

The SIR-C and SAR-X will share a common antenna structure and some electronics logic. SIR-C can be either electronically or mechanically scanned; SAR-X is mechanically scanned by physical movements of the antenna. The two radars can operate either independently or together at the same repetition rates.

During the year, a prototype SIR-C was flown aboard NASA's DC-8 aircraft and mapped only local areas, or "anchor sites." Future SARs, planned for the Earth Observing System, will eventually expand the mapping capability to include global coverage. With global surveys and the use of multiple wavelengths, polarizations and incidence angles, scientists should be able to characterize Earth's surface and its cover.

NASA's European partners for the Space Radar Laboratory are Germany's Bundesministerium fuer Forschung und Technologie and Italy's Consiglio Nazionale delle Ricerche. The European SAR-X was designed and developed by Deutsche Forschungsanstalt fuer Luft- und Raumfahrt and Agenzia Spaziale Italiana.

Microwave Sounding Unit

The microwave sounding sensors developed by JPL for weather satellites operated by the National Oceanographic and Atmospheric Administration (NOAA) are significantly improving weather predictions in the United States. So far, 8 of the 12 instruments built by JPL since the late 1970s have been sent into space. The remaining 4 instruments are scheduled to follow during the next five years.

Each Microwave Sounding Unit consists of four radiometers that sense microwave emissions at 50.3 to 57.95 GHz. Mounted in NOAA's TIROS medium-altitude satellites, the units laterally scan Earth in a cross-track nadir mode at the rate of 11 scenes per scan. These units provide a minimal spatial resolution of 109 kilometers (67 miles).

The Microwave Sounding Unit and companion infrared sensors aboard TIROS satellites have produced an impressive quantity of highly accurate weather and climate observations. The microwave units allow surface and atmospheric temperatures to be determined under any weather condition. Sophisticated computer algorithms developed for JPL's planetary studies have analyzed these data and have produced a record of Earth's climate since 1978.

Atmospheric Infrared Sounder

NASA has selected JPL's Atmospheric Infrared Sounder (AIRS) as a facility instrument to fly aboard the Earth Observing System's first polar-orbiting platform (EOS-A). The EOS-A is part of "Mission to Planet Earth," NASA's project to monitor and study Earth's environmental changes using Earth-viewing satellites.

This sounder will measure atmospheric temperature and moisture, producing more accurate data than are currently available on the Earth's atmosphere, land mass and oceans. These data are useful for studying climatic changes and variations, detecting increased greenhouse gases, monitoring global energy and water cycles, tracking the interactions between Earth's atmosphere and surface and improving weather predictions.

During the year, the AIRS project successfully completed a baseline design and parametric analysis. The baseline permits simultaneous and accurate measurements of Earth's infrared radiation between 3 and 15.4 microns in 4,000 high-spectral resolution channels. The Laboratory also began developing cryogenic coolers and long-wavelength infrared detectors for AIRS.

The project is designed to satisfy NASA's requirements for global change research programs and NOAA's operational needs for better weather prediction.

Computer algorithms have been tested for retrieving various weather data, including land and ocean surface temperature, atmospheric humidity and cloud distribution, total ozone levels, snow and ice cover distribution, surface albedo and minor greenhouse gases like methane. These data are typically more accurate or sensitive than any others acquired to date; for example, atmospheric temperature profiles have been drawn to 1 degree and 1 kilometer (0.6 mile) vertical resolution, compared to previous measurements of 2.5 degrees and 2.5 kilometers (1.6 mile).

PLANETARY SCIENCE

Solar System Radar

Using the Very Large Array antenna at Socorro, New Mexico, Caltech and JPL astronomers obtained captivating images of the rugged Venusian terrain. These data complement those returned by the Magellan spacecraft.

The astronomers used the 70-meter Deep Space Network station at Goldstone, California, to transmit signals and the Very

Large Array antenna complex, operated by National Radio Astronomy Observatory, to receive radar echoes from Venus. The 27 antennas of the Very Large Array provided a resolution equivalent to that of a single, much larger telescope with a diameter approximating the distance over which the antennas are spread.

Some of the more elevated regions on Venus — initially viewed by the Pioneer Venus Orbiter and later by the Magellan spacecraft — appear especially bright at the four-centimeter wavelength. The brightness may indicate a surface with high metallic content, possibly iron pyrite, or "fool's gold."

During July astronomers used the Goldstone Network-Very Large Array combination to repeat last year's observations of Saturn's moon Titan. This time they improved the experiment by measuring both circularly polarized reflection modes. Based on these returns, researchers believe that Titan's surface is a highly reflective, multiple-scattering structure such as ice. These properties may be similar to those of Jupiter's giant satellites.

Preliminary analysis of two years of data indicates Titan could be nutating (wobbling) significantly about its postulated synchronous axis of rotation — a finding that, if verified, could bear on the design of instruments for the Cassini mission to Saturn.

This was also a busy year for observing asteroids with the Goldstone radar. Two Earth-approaching asteroids — 1990 MF and 1990 OS — were observed in July and August. Ranging to 1990 MF provided the highest precision radar measurement to a solar system target (0.375 microsecond).

At a round-trip light time of 33 seconds, this ranging was the smallest fractional precision radar ranging ever done. Based on Doppler frequency shift observations made of 1990 OS from Goldstone, scientists were able to determine the orbital parameters of this object well enough to predict the asteroid's future close Earth passages. The asteroid Prokne was also observed by Goldstone, making it the first main-belt asteroid to be observed and the first object with a diameter of 200 kilometers (124 miles) to have its radar reflection properties measured at four centimeters.

INFORMATION SYSTEMS

Solar System Visualization

The Solar System Visualization project converts imagery generated by 25 years of NASA's successful planetary exploration into useful materials for further scientific research and general education. The project produced video segments of the Neptune encounter; these segments show the complex dynamics of Neptune's Great Dark Spot and the unusual topography and geyser-like plume of Neptune's moon Triton.

During the year, the project developed visualization techniques that graphically depict time-dependent planetary phenomena and perspective views of three-dimensional topography; the techniques were used to compare spacecraft images with computer models of atmospheric dynamics.

Visualization is a powerful tool that graphically depicts new discoveries of interest to the scientist and layperson alike. Two collections — one of the Voyager Neptune encounter highlights and the other a Voyager science summary — were released as educational products last year to widespread acclaim. Many sequences from these products were featured on public television in October in two hour-long NOVA programs on Voyager. The project also produced a special video segment showing the rotation of Asteroid 1989 PB. In addition, some Magellan returns of Venus have been transformed into dramatic videos that recreate a sweeping ride over the planet. New products on the Magellan, Galileo and Mars Observer projects are also being planned.

Planetary Data System

An initial version of the Planetary Data System, a repository designed to receive and archive data from each of JPL's planetary missions and make them readily available to the scientific community, became operational this year. NASA has selected seven groups of planetary scientists to manage separate nodes for geoscience, planetary atmospheres, plasma interactions, particles and fields and planetary imaging and small solar bodies. Because the nodes are inter-linked with one another and the system's central node through a computer network, they are a great resource for other scientists seeking access to the data.

This computer-based data archive and distribution system contains information on approximately 80 data sets from planetary missions. Some of the most important data are contained on compact disks. The system has been designed for easy access. Scientists can search the catalog on line, identify what they want and automatically access the appropriate node where they can browse the data. Orders are filled by the nodes, or if bulk orders are desired, by the National Space Science Data Center.

Navigation Ancillary Information Facility

The Navigation Ancillary Information Facility (NAIF) is a NASA-funded activity that in cooperation with scientists throughout the world restores old space science data sets and archives new data. The facility's ancillary data information system assembles, archives and offers easy user viewing access to geometry used to interpret observations of bodies within the solar system. The system can quickly correlate individual instrument data sets with data obtained from other spacecraft instruments.

During the year, the NAIF activity was able to retrospectively pinpoint precisely where Voyager's instruments were pointed during flybys of Jupiter, Saturn and Uranus. The restoration aided Voyager scientists and other investigators in understanding the mass of information returned from Voyager's scientific instruments.

Fresh from its Voyager success, the NAIF system was used for the Galileo Venus flyby and, in its first real-time application, for the Magellan radar mapping mission. Currently researchers are tailoring the ancillary data information system to Mars Observer and CRAF/Cassini missions. Engineers and scientists in the Soviet Union are similarly adapting the system for their next Mars project, scheduled for a 1994 launch.

The international teams of investigators on these space projects have become enthusiastic supporters of the NAIF system because it simplifies data, making it easier to interpret observations from spaceborne instruments.

Infrared Processing and Analysis Center

The Infrared Processing and Analysis Center (IPAC), established six years ago to assist astronomers in accessing data obtained from the successful Infrared Astronomical Satellite (IRAS), achieved new goals this year. In October, the Center made available to the astronomical community a high-resolution processor that significantly increases the resolution of IRAS data. An on-line data retrieval service, the NASA/IPAC Extragalactic Database, was also opened at the Center during the year. This service provides data on extragalactic objects either by name or by position, a listing of abstracts of significant articles published since 1988 and a bibliography of related research articles. By year's end, the data base contained more than 200,000 names for approximately 120,000 objects (some have more than one designation) and nearly 150,000 pointers connecting individual objects to a bibliographic reference.

The Center reprocessed all IRAS survey data and produced a faint source catalog of more than 173,000 sources. This new publication contains sources 2.5 times fainter than those in the original IRAS catalog; and for regions of the sky away from the galactic plane, it now contains more than twice as many sources as before.

Approximately 50 astronomers visited the Center during the year. Each astronomer remained two to five days, consulting with the resident science staff and data-processing specialists and using the facilities for image and data processing.

As more guest investigators submit individual requests for special IRAS data processing by remote access, the Center is making remote-access research an integral part of its operation. The Center currently receives about 10,000 individual data-processing requests a year from several hundred astronomers worldwide.

ASTRONOMY AND SOLAR PHYSICS

Cosmic Ray Monitor

A cosmic ray monitor, fabricated from standard CMOS (charged metal-oxide semiconductor) chip technology, was sent into space aboard the Combined Release and Radiation Effects Satellite in July. A more advanced version of this detector will be included in the Mid-Course Space Experiment planned for launch in 1992. The detector is being proposed for all satellites and will be used to monitor the cosmic ray environment around critical electronic circuitry, such as the spacecraft computer.

The detector is a modified static random access memory chip that is sensitive enough to discriminate between light ions (such as protons and alpha particles) and heavy ions (such as oxygen and iron).

Astro Star Tracker

Designed and built by JPL, the Astro Star Tracker performed outstandingly as part of the Marshall Space Flight Center's Astro-1 Ultraviolet Observatory that was flown in December aboard the Space Shuttle Columbia.

Originally, the tracker's only function was to stabilize the observatory's pointing system during the long exposure times required for scanning faint astronomical objects. However, when software problems caused the pointing system's three primary star trackers to fail, the Astro Star Tracker took over the target acquisition function as well. The tracker performed superbly, salvaging scientific results.

Soft X-Ray Telescope Camera

The Japanese Solar A satellite, scheduled for launch in 1991, will study solar flares on our nearest star, the Sun. The satellite will carry a soft X-ray telescope camera, its primary instrument, which was jointly developed by JPL and the Lockheed Corporation.

The camera can take pictures of solar flares every two seconds, providing researchers with an almost film-like record of these poorly understood events. With these data, scientists can infer temperatures within the flares and can study the relevant physical processes.

"Window Curtain" Structure

New images made with JPL's Wide Field/Planetary Camera on NASA's Hubble Space Telescope have stirred great excitement among astronomers. The pictures, obtained despite flaws in the telescope's primary mirror, revealed the structure of a thin sheet of gas located at the edge of the famous Great Nebula in Orion, an estimated 1,500 light-years from Earth. The Orion Nebula is a

"stellar nursery"—a region where new stars are forming out of interstellar gas. Astronomers compare the motion of this gas sheet to a rippling window curtain; they believe the sheet traces the boundary between the hot, diffuse interior of the nebula and an adjacent dense, cool cloud.

The gas sheet is visible in light emitted by atoms of gaseous sulfur; the sheet appears strongest in those zones between the nebula interior and the dense cloud. The sulfur emission breaks into clumpy and filament-like structures down to sizes at the limit of the telescope's resolving capability. In contrast, emissions from gaseous oxygen and hydrogen appear to be coming from the interior of the nebula and are distributed much more evenly in the image.

The source of the sulfur emission observed in the images is a region where intense ultraviolet radiation from a cluster of hot, young stars is "boiling off" material from the face of a nearby cloud. This cloud is where hot stars are formed.

Astronomers claim that these images show how the Hubble Space Telescope can be used to obtain scientifically significant data with a clarity far exceeding that normally obtained from ground-based instruments. The images obtained were computer processed to partially correct for the halo effect caused by the telescope's spherical aberration.

Wide Field/Planetary Camera Exchange

The Wide Field/Planetary Camera 2 (WF/PC 2), a replacement for WF/PC, will be installed in the Hubble Space Telescope by astronauts during a shuttle mission scheduled for June 1993. The replacement was originally planned when scientists realized that the longevity of Hubble's instruments would not meet the telescope's 15-year mission timeline.

Now the need to correct the primary mirror's optical aberration imposes new design challenges for the WF/PC 2. The flaw in Hubble's 8-foot (2.4-meter) primary mirror prevents the otherwise perfectly functioning WF/PC from focusing properly. Consequently, late in the year Laboratory scientists were preparing an adaptive optics design that would enable WF/PC 2 to compensate for the telescope's flaw and permit sharper camera focusing. The original WF/PC 2 delivery date also is being advanced.

The replacement camera will be similar to the first but with added spectral capability in the ultraviolet region. As Hubble's workhorse, the WF/PC will return images that will help astronomers better understand the birth and evolution of the universe.

Southern Hemisphere Radio Astronomy

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Last year, the 70-meter antenna of the Deep Space Communications Complex at Canberra became the largest and most sensitive radio telescope for centimeter wavelength observations in the Southern Hemisphere. The antenna's low-noise amplifier was refurbished to extend its radio astronomy frequency coverage from a range of 13.8–15.8 GHz to 13.0–17.5 GHz. The antenna's broadened frequency coverage and added reception sensitivity are invaluable for microwave spectroscopy, which measures spectra found in the gases of star-forming clouds. Most complex molecules, such as formaldehyde and methyl alcohol, have their main emission lines in this spectral region.

JPL manages the Deep Space Network (DSN), NASA's worldwide system for communicating with spacecraft traveling beyond Earth orbit. The DSN supports high Earth orbiters not visible to the Tracking and Data Relay Satellite System (TDRSS) and in emergencies backs up missions normally supported by this system. The DSN also supports missions in their launch phase for NASA and, on a reimbursable basis, for foreign space agencies such as the European Space Agency (ESA).

The DSN sites are located at Goldstone in Southern California's Mojave Desert; near Madrid, Spain, and near Canberra, Australia. The three locations are separated by approximately 120 degrees longitude so that as the Earth turns on its axis, a distant spacecraft is almost always in view of one of the stations. Combined, DSN has more than a dozen antennas, ranging in size from 26 meters (85 feet) to 70 meters (230 feet) in

diameter. The 26-meter antennas are used for near-Earth operations; the 70-meter antennas provide deep space support. The Network Operations Control Center located at JPL controls and monitors operations at these sites.

The Laboratory also manages telecommunications activities for other NASA-assigned programs. JPL's spacecraft radio development program ensures compatibility between flight and ground radio systems for solar system exploration. The Laboratory conducts advanced development and demonstration of deep space communications and radio navigation components and systems; participates in NASA's Search for Extraterrestrial Intelligence (SETI) Project; manages the Goldstone Solar System Radar, and leads a small radio astronomy program using DSN facilities, often in conjunction with radio astronomy observatories. Its flight and ground radio-science program uses spacecraft signals to probe the interplanetary medium. Finally, JPL spearheads a space frequency management program that ensures the availability of frequency assignments nationally and internationally for NASA's deep space missions.

OVERVIEW

During 1990, the DSN supported a record 29 spacecraft ventures: the Magellan, Galileo and Ulysses deep space missions; 9 other NASA spacecraft in extended deep space missions; ESA's Giotto deep space mission and Hipparcos high Earth orbiter mission; 3 previously launched NASA near-Earth missions; the Japanese Hiten Lunar mission, and 5 NASA and 6 foreign reimbursable launches. The DSN personnel also discussed operational cross-support arrangements with space agencies in Canada, France, Japan, Italy and the Soviet Union as well as with the National Radio Astronomy Observatory.

MISSION SUPPORT

Magellan

In preparation for Magellan's extensive mapping of Venus, the DSN began planning mission support in 1982. The Magellan spacecraft would be transmitting data at the highest data rate ever — 268.8 kilobits per second for two out of every three hours during the eight-month mapping cycle — placing a heavy burden on DSN's telemetry system.

To meet the mission's requirements, the receiver and the baseband assembly were modified to reduce the telemetry acquisition time to 1 minute; in previous missions, the acquisition time was between 5 and 20 minutes. The DSN also added a new Fast Fourier Transform algorithm that reduces the receiver's signal lockup to less than 20 seconds and made modifications to the baseband assembly that compress sub-carrier acquisition and processing time to less than 40 seconds. As a result of these modifications, the DSN safely met the one-minute Magellan requirement.

Other significant telemetry system modifications were made as well. An additional Maximum Likelihood Convolutional De-

coder allows simultaneous processing of two-coded telemetry streams. A digital data recording assembly increases the magnetic tape capacity from 10 minutes to over one hour.

In August, the 70-meter antenna receivers at Goldstone and Madrid locked on to the Magellan downlink as the spacecraft emerged from Venus occultation. After a short in-orbit checkout, both the Magellan Project and DSN team were poised for the spacecraft's prime objective — radar mapping of the entire globe of Venus.

During late August and early September, the DSN intensified Magellan support to correct a signal loss that occurred on August 17 and again on August 22. By early September, JPL had successfully restored the spacecraft to full function, and on September 15, Magellan began mapping operations, using the two 34-meter antennas at Goldstone.

DSN support of Magellan's mapping operation has been exemplary. During the first 30 mapping days, the overall DSN data capture rate reached 98.6 percent, exceeding DSN's projection by nearly 3 percent. Magellan's stunning images of Venus are evidence of DSN's superb performance.

Galileo

After a successful launch on October 18, 1989, the Galileo spacecraft was placed on a Venus trajectory by the Inertial Upper Stage (IUS). Once the IUS separated from the spacecraft, DSN's 34-meter antennas immediately began tracking Galileo and personnel began preparing the spacecraft for the six-year journey to Jupiter.

Because the spacecraft was pointed toward the Sun, the low-gain antenna was not optimally pointed to Earth during this portion of the mission. The condition degraded telecommunications link performance and reduced telemetry bit rates for the engineering and science return. To compensate for this condition, the DSN supported all Galileo tracking passes after the first few weeks with 24-hour coverage using the 70-meter antenna.

In December 1989, an elevation bearing failed on Madrid's 70-meter antenna. Tracking schedules were rearranged while the antenna was being repaired. The antenna was back in service on February 1, in time to bring the DSN to full strength for Galileo's Venus encounter on February 9.

Because Galileo's high-gain antenna remained furled during the Venus encounter, the DSN transmitted imagery data through the spacecraft's low-gain antenna. To obtain imagery data using the low-gain antenna, the DSN had to play back several Venus images at a relatively low speed of 1,200 bits per second.

The DSN provides precision ranging and Doppler navigation data required for the correction maneuvers that place Galileo on its Venus-Earth-Earth gravity-assist trajectory. The data supplied have met or exceeded prelaunch commitments in quality and quantity. In addition, a powerful new navigation data technique, the Delta

Differential One-Way Ranging (Δ ODOR), was used in Galileo operations. This technique allows the spacecraft's angular position to be measured quickly and accurately; measurements are determined by the differences in arrival times of special tones modulated onto the spacecraft downlink signal. The technique also allows DSN controllers to quickly update the spacecraft's orbit. The excellent Δ ODOR results improved targeting conditions for the first Earth encounter on December 8.

To prepare for the tracking support of this brief Earth encounter, the DSN conducted training sessions for key personnel and developed plans for a comprehensive series of exercises simulating the spacecraft's Earth encounter.

Ulysses

The DSN supported the launch and subsequent operations of Ulysses, the joint ESA and NASA mission to explore the Sun's polar regions. The spacecraft arrived at the Kennedy Space Center after delivery from the European Space Research and Technology Center in mid-May. On June 25, a brief spacecraft compatibility test was performed by the Cape Canaveral DSN facilities, and final preparations for the spacecraft's launch on October 6 aboard the Space Shuttle Discovery were made.

Giotto

Giotto — the ESA's first deep space mission and one of five international spacecraft to explore Halley's Comet during its solar passage in April 1986 — was reactivated in 1990. For several years, the ESA had planned to reactivate Giotto, but heavy DSN tracking

commitments precluded any mission support planning until the end of 1988. NASA agreed to provide Giotto ground support in exchange for the use of ESA's masers at Australia's Parkes Radio Astronomy antenna during the two Voyagers' Uranus and Neptune encounters.

Final operational testing and training were concluded in February, shortly before Giotto's reactivation. The DSN began operational support on February 19, after several hours of telecommands originating at the European Space Operations Center in Darmstadt, Germany, were transmitted by DSN's 70-meter station near Madrid, Spain. Extensive commands were necessary because of uncertainty about the spacecraft's configuration.

Later that same day, the identifying radio signal appeared on the signal spectrum indicator analyzer at Madrid's 70-meter station. Distance to the spacecraft exceeded 100 million kilometers (approximately 62 million miles), or slightly more than 12 minutes round-trip light time. Because the DSN needed sufficient time to check the science instrument payload, it borrowed support time from other flight projects. Checkout was completed on May 18.

In June, DSN began supporting spacecraft maneuvers to position Giotto for an Earth gravity assist on July 2. The spacecraft would then be placed on course for the 1992 encounter with the Comet Grigg-Skjellerup. As the spacecraft cruised within 28,000 kilometers (17,398 miles) of Earth, picking up a gravity assist, controllers were able to determine Giotto's new orbit.

The spacecraft was placed in a hibernation mode on July 31, completing DSN's successful Giotto support.

FACILITIES

Ka-Band Research

JPL is exploring technology for Ka-band frequencies (wavelengths of approximately one centimeter) that will be used by the DSN for future deep space missions, possibly starting with CRAF/Cassini missions. This higher frequency band promises greater data capacity — increasing by as much as a factor of 10 — but is subject to moisture attenuation. To obtain better high-frequency performance, DSN's large dish antennas will be outfitted with beam waveguide microwave optics, similar to the optical path arrangement on the Hale Telescope at the Palomar Observatory in California.

The 26-meter Venus Station at Goldstone has traditionally served as the field laboratory for developing and demonstrating DSN technology. Unfortunately, the Venus Station's aging dish antenna cannot support Ka-band or beam waveguide experimental investigations. To meet the Ka-band requirements, a new 34-meter beam waveguide antenna has been built at Goldstone. This new antenna, designed for microwave research at different frequencies, was completed in May.

The new antenna will serve as a prototype for both new DSN antennas and for beam waveguide upgrades of existing antennas. It will be used extensively for Ka-band technology development, including spacecraft communications system experiments. The Mars Observer spacecraft, scheduled for launch in 1992, will carry a Ka-band source for the first experiment.

The new antenna's center-line beam waveguide, which resembles a three-meter-diameter storm drain, channels microwave energy from the apex of the main reflector to the center of the antenna foundation, below ground level. An alternative, or bypass, configuration has been designed so that energy bounces off a mirror placed near the main reflector apex and is collected by a beam waveguide assembly outboard on the reflector's central structure. The center-line configuration will be used in new antennas and the bypass configuration in upgrades on existing antennas.

The new antenna's performance at X-band and Ka-band appears to confirm analytical predictions. Microwave holography has also established and refined the main reflector figure and determined the phase and amplitude distortions of the beam waveguide system. The reflector surface has a root-mean-square accuracy of 0.45 millimeter according to holography-derived phase image tests. These results promise good Ka-band performance.

The 34-meter beam waveguide antenna is operating as a field laboratory for future DSN service, replacing the Venus Station. The Venus Station is still in operation but its functions have been reduced.

Beam Waveguide Subnetwork

The new 34-meter beam waveguide antenna at Goldstone serves as a prototype for a network of beam waveguide antennas planned for each DSN site. During the year, plans for replacing one of two 34-meter antenna stations at each site were completed. The current 34-meter antennas, which have been modified several times over the years, are difficult to focus and costly to maintain; each has logged more than 20 years of operation.

Construction of a Goldstone antenna will begin in 1991 and is scheduled for completion in 1993; construction of the Madrid and Canberra antennas should be completed by 1994-95.

TELECOMMUNICATIONS TECHNOLOGY

Global Positioning System

The Department of Defense's Global Positioning System (GPS) is a network of high Earth orbiting navigation satellites that when fully implemented will provide 15-meter positioning accuracy, allowing scientists to determine variations in Earth's orientation. A full constellation of 24 satellites is planned; currently, GPS has 15 satellites in orbit.

Using signals from GPS's current configuration, JPL scientists were able to determine, by interferometric techniques, the DSN station positions and Earth's orientation — within one two-millionth of a degree. These measurements were made with a 26-meter antenna, freeing DSN's overburdened 70-meter antennas for more pressing spacecraft support tasks. In the future, even smaller ground antennas will be sufficient for these measurements. And once GPS is fully in

place, the accuracy of these measurements should increase, allowing scientists to determine precisely Earth's orientation — a measurement required for spacecraft navigation.

Superconducting Cavity Maser Oscillator

The Superconducting Cavity Maser Oscillator — developed at JPL this year — could offer as much as 10 times greater operational stability than the hydrogen maser, presently the best standard. The improved stability of the new maser would enhance gravitational wave experiments.

The stability of the new maser oscillator exceeds that of the hydrogen maser at averaging intervals from 1 to 800 seconds, which is at least one order of magnitude better. At these averaging intervals, the new maser's stability was found to be one part in one hundred trillion. However, these measurements, made by JPL's Frequency Standards Test Facility, were limited by test system noise. Theoretically, the new maser's stability is expected to be one part in one quadrillion for the same averaging intervals. These frequency standards are required for DSN's communications, navigation and radio-science tasks.

The Superconducting Cavity Maser Oscillator will enhance Galileo's gravitational wave experiments. For example, when the stability of the hydrogen maser reaches several parts in one quadrillion for averaging intervals of a few thousand seconds, gravitational wave detection experiments can be performed when the spacecraft's distance to Earth is a few thousand light-seconds. However, with the superconducting maser oscillator similar experiments are possible at much closer proximity.

Digital Receiver Demonstration

The Advanced Receiver Exciter II (ARX II), a prototype for the next generation of DSN receivers, is more sensitive and controllable than current DSN receivers. When the Pioneer 11 spacecraft, now beyond the solar system, had problems in October, DSN's new ARX II was rushed from JPL to Goldstone. Within 24 hours, the ARX II was tracking the spacecraft's signal well enough to detect an oscillator as the probable source of the problem. Based on the ARX II's performance, DSN decided to track the spacecraft in a one-way mode.

Big Viterbi Decoder for Galileo

A new channel coding applied to Galileo's downlink data is expected to increase the mission's science return by 30–100 percent during the 1995 Jupiter and Io encounters. These new codes require less power than uncoded transmission for the same bit error rate. As an example, Voyagers 1 and 2 use a short convolutional code that requires a data bit signal-to-noise ratio of approximately 2.5 dB (1.8 to 1) to achieve a bit error rate of 1 in 200 for returning good quality uncompressed images. In recent years, JPL engineers have identified other convolutional codes requiring a still lower signal-to-noise ratio. One such longer convolutional code offers a 50-percent improvement over the Voyager short code.

Spacecraft hardware requirements for these longer codes are modest; however, until recently, the ground hardware requirements for these codes were impractical. Using Very Large Scale Integrated (VLSI) circuitry has simplified building a high-speed decoder for the longer code. A suitable decoder can now be compressed into a modest-sized package. With VLSI circuitry and algorithm improvements, the new decoder can be 256 times smaller than its predecessor.

Launch delays following the Challenger accident threatened the Galileo mission with reduced communications capability and, subsequently, reduced science return. To increase the volume of data returned by Galileo, a new convolutional encoder based on the JPL-generated codes was added to the spacecraft. At the same time, JPL began designing and constructing a new Big Viterbi Decoder.

The Big Viterbi Decoder uses 256 identical VLSI chips, connected in a parallel processing arrangement, for decoding. The VLSI chips have been fabricated and tested; initial system tests on a major portion of the new decoder have shown that it performs as expected. When Galileo unfurls its high-gain antenna in 1991, the spacecraft will use the new decoder for data transmission. The decoder modules will be deployed throughout the DSN for Galileo support.

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Solid-State Lasers for Space Communication

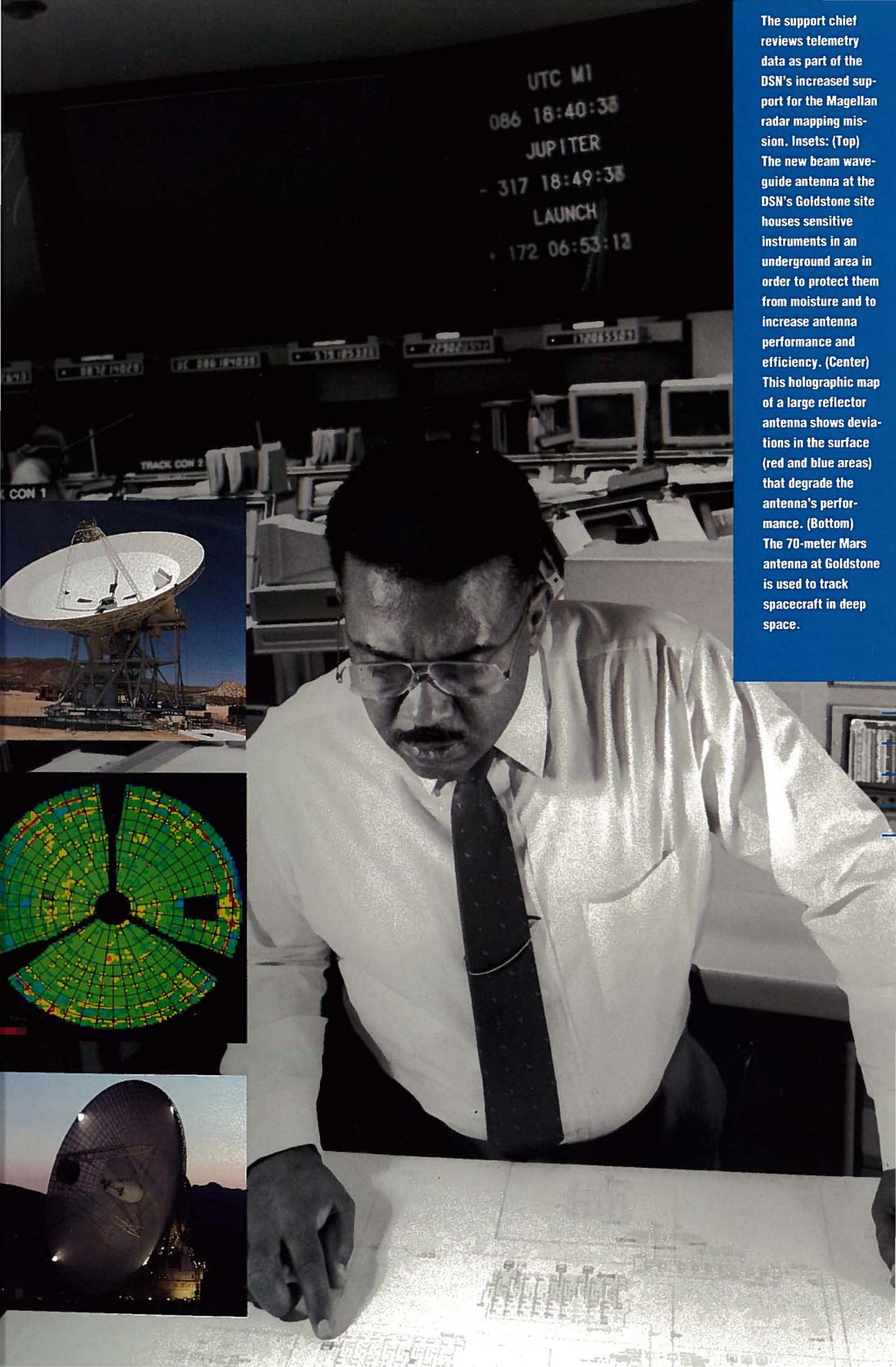
JPL has developed and demonstrated a solid-state laser transmitter that emits modulated pulses of green light. This diode-pumped, yttrium aluminum garnet laser is expected to significantly improve optical communications for future space missions, which will require tightly focused beams and small components. The peak power output of the laser transmitter is seven kilowatts, which is sufficient for deep space missions, and its energy pulse of 150 microjoules meets the energy requirements necessary for exploration of both the inner and outer planets of the solar system.

Search for Extraterrestrial Intelligence

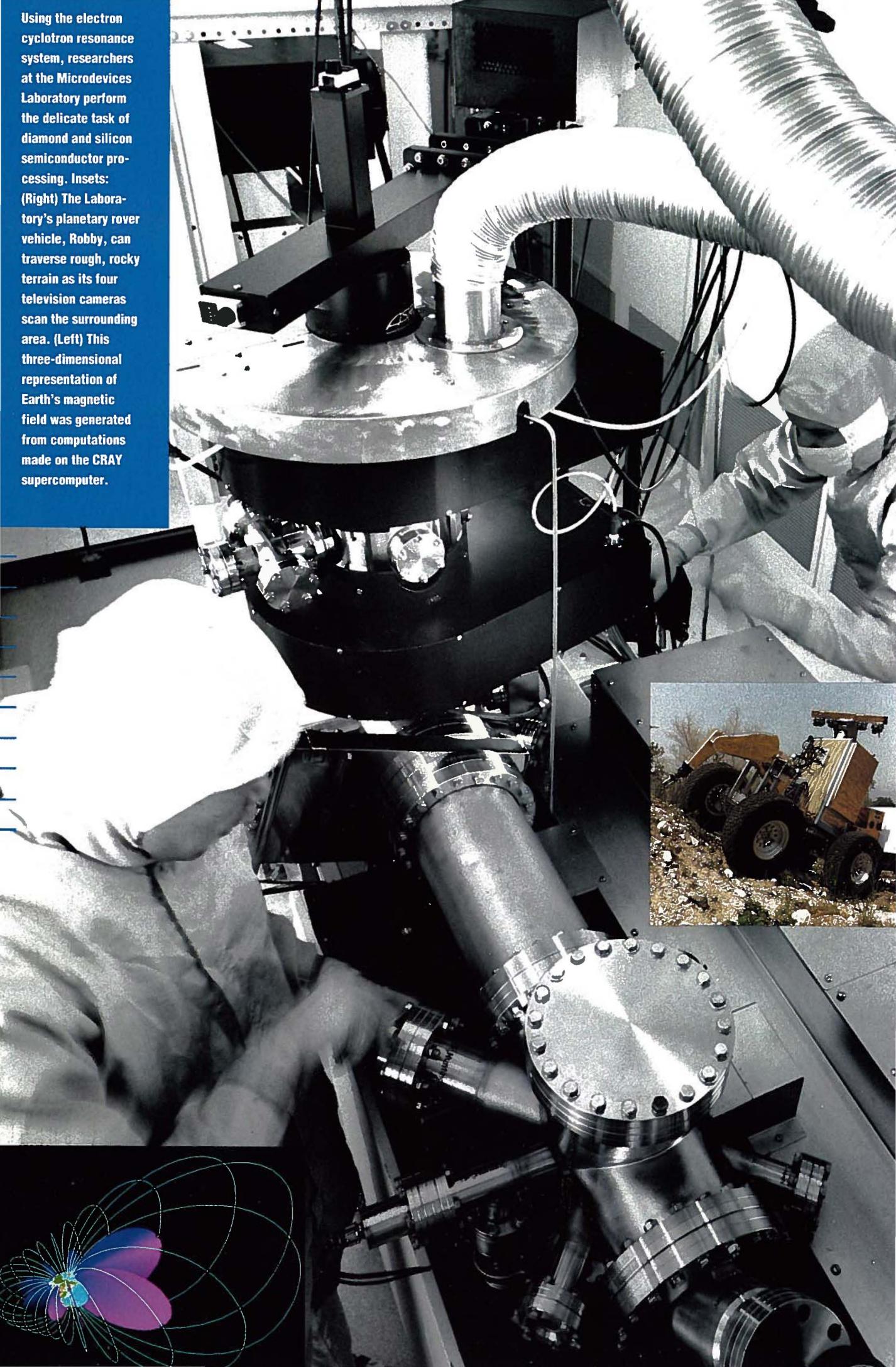
A two-million channel, digital wideband spectrum analyzer and signal processor system, designed and built by JPL for NASA's Search for Extraterrestrial Intelligence (SETI) Project, was demonstrated by JPL's SETI team during the year. The spectrum analyzer uses a pipelined Fast Fourier Transform architecture that performs 4.5 million operations per second, exceeding the speed of current supercomputers. Designed for a variety of DSN radio measurement applications, the system will serve as a prototype processor for the SETI Sky Survey.

The JPL team demonstrated the special-purpose software modules. These modules will accommodate the anticipated high data volume and will minimize the difficulty of detecting potentially weak interstellar signals in the presence of radio frequency interference. JPL is working with NASA's Ames Research Center in carrying out the NASA SETI Microwave Observing Project.

The support chief reviews telemetry data as part of the DSN's increased support for the Magellan radar mapping mission. Insets: (Top) The new beam waveguide antenna at the DSN's Goldstone site houses sensitive instruments in an underground area in order to protect them from moisture and to increase antenna performance and efficiency. (Center) This holographic map of a large reflector antenna shows deviations in the surface (red and blue areas) that degrade the antenna's performance. (Bottom) The 70-meter Mars antenna at Goldstone is used to track spacecraft in deep space.



Using the electron cyclotron resonance system, researchers at the Microdevices Laboratory perform the delicate task of diamond and silicon semiconductor processing. Insets: (Right) The Laboratory's planetary rover vehicle, Robby, can traverse rough, rocky terrain as its four television cameras scan the surrounding area. (Left) This three-dimensional representation of Earth's magnetic field was generated from computations made on the CRAY supercomputer.



In optics, automation and robotics, microelectronics and supercomputing, JPL scientists and engineers are continually exploring concepts and developing prototypes for the space systems of tomorrow. JPL's advanced technology efforts are the foundation for all NASA's planetary missions, providing innovative engineering and scientific procedures and techniques essential to future space exploration.

TECHNOLOGY FOR ADVANCED OPTICAL SYSTEMS

The Technology for Advanced Optical Systems Office was established in 1989 to explore the visible, infrared and submillimeter regions of the electromagnetic spectrum and to develop technology that would eventually be required for space astrophysics, extrasolar planet detection, Earth remote sensing, planetary exploration and optical communications programs. This project, funded by NASA and the Department of Defense (DOD), will strengthen JPL's already substantial capabilities in optical systems technology while exploring new areas for optical research and application.

Precision Segmented Reflectors

In the future, large imaging telescopes and optical communications receivers will require big, multisegmented, lightweight reflectors. JPL is developing such units in its Precision Segmented Reflectors Program.

This program has demonstrated a breadboard actuator capable of controlling a panel to an accuracy of one micron. The program is also exploring the technology that would be used to control a multi-segmented reflector, including sensors for figure initialization and maintenance.

Techniques are being refined to manufacture panels of the shape and size needed for a proposed astronomy mission that would explore the submillimeter region of the electromagnetic spectrum — a transitional region between infrared and radio wavelengths. Graphite-epoxy composite panels, two to three times lighter than lightweight glass, were developed; these panels have a surface accuracy of better than two microns root mean square. JPL has also recently developed advanced composite materials that are cyanate based and, therefore, are more resistant to space environmental degradation than presently used compounds.

Control Structure Interaction

The Control Structure Interaction Program is developing the technology to shape reflectors with microprecision and to damp vibrations in large optical or antenna systems in space. A space-based optical interferometer, planned for some future mission, would require a reflector that holds steady to within one nanometer to eliminate jitter.

Last year, the program produced a new type of active strut for precision structures that reduces perturbing effects to the nanometer level. This level of vibration is much lower than that found in commercially available actuators.

JPL has also developed impedance-based local controllers that "de-tune" resonant structures and provide independent control of stiffness and damping — important parameters for maintaining the structural stability of large space systems.

These impedance-based controllers and other advanced control-structure components are being incorporated into a test-bed to begin validating JPL's "multilayered approach" to reduce vibration; this approach isolates vibrating machinery and damps whatever vibrations enter the structure, actively stabilizing the sensing system. By late 1992, this approach is expected to reduce by a factor of 1,000 the effect of vibration on optical interferograms.

Precision Optical Delay Lines

Precision optical delay lines — a component of optical interferometers that maintains the fringe pattern essential to interferometry — will have applications in both astrometry (measuring stellar positions) and high-resolution imaging. These delay lines are being demonstrated in ground-based instruments, and eventually they will be used in future space applications.

A precision optical delay line installed at the 30-meter Mark III Optical Interferometer baseline at Mount Wilson Observatory measured angular separations between stars in the Hyades cluster to an accuracy of 2 percent, one order of magnitude better than previous measurements. These same observations improved the presently accepted measurement of distance to Hyades to an accuracy of, coincidentally, 2 percent.

With U.S. Navy funding, an advanced delay line is being developed for a 300-meter interferometer baseline that will require 10 times the tracking velocity of the Mark III system while still retaining the original one-nanometer precision of the earlier instrument. The baseline, which will be part of an advanced interferometer being built in Northern California by the Navy, uses layered-vibration isolation to achieve this performance level. Combined with the Control Structure Interaction Program, optical delay line technology will enhance space-based optical interferometry research into the 1990s.

Integrated Modeling of Optical Systems

Integrated Modeling of Optical Systems is a new analytical computer program for complex optical-system architectures. The program can model the optical line-of-sight or full-wave-front performance of optical systems subject to thermal and dynamic dis-

turbances. The program accommodates the most common optical elements (flat and conic mirrors and lenses, reference surfaces and focal planes) and accounts for some uncommon optics such as segmented and deformable mirrors.

Advanced Optical Materials

Scattered light emitted from conventional optical surfaces limits a space telescope's ability to resolve dim objects or other fine details in the vicinity of bright stars. To improve the resolution of space telescopes, JPL is developing advanced materials and fabrication processes for optical components. These components will feature both broad optical response bandwidths and low light-scattering properties at the small angles between incident and reflected light. Space telescopes and interferometers of the future will require this kind of advanced technology to study astrophysical objects and to search for planets around other stars.

Current mirror technology can produce either broad optical response performance or low light-scattering properties over narrow bandwidths, but not both capabilities on the same surface. JPL, therefore, is developing polishing and coating technologies that will yield both capabilities. Small, ultra-smooth mirror surfaces with broadband reflectivity have been made. Compared with commercial mirrors, they reduce scattered light a hundredfold at small angles. The Laboratory is also investigating how well these processes can be scaled up for larger mirrors; the ultimate goal is to produce one-meter mirrors that have both broadband response and low light-scattering properties.

Micrometrology Sensors

JPL is conducting research on metrology sensors and systems that measure the separation of optical elements down to subnanometer levels over distances of

several meters. These sensors are used to calibrate the internal geometry and alignment of large optical systems. JPL has produced a novel design that combines simple sensors, capable of one-dimensional measurements only, into a system that precisely measures the complex, three-dimensional positions of numerous elements. An advanced metrology sensor is currently being fabricated to measure absolute distances between optical elements to nanometer-level accuracies over distances of 15 meters (49 feet).

For still more accurate measurements, JPL scientists are testing an advanced sensor that eliminates transmissive optical elements from the sensing path, thus reducing errors caused by temperature changes.

OTHER TECHNOLOGICAL ADVANCES

Sorption Cooler Technology

JPL is investigating, for both NASA and the DOD, cryogenic sorption coolers that can cool science instrument detectors to temperatures as low as 10 kelvin. These devices are a chemical alternative to the mechanical compressors used in refrigeration systems. Sorption refrigeration is the only cryogenic technology with the potential of operating both reliably and vibration-free in space for more than 10 years. Coolers of this type are relatively easy to integrate with sensors and may be scaled to varying cooling loads.

Using recently developed heat regeneration techniques, researchers have demonstrated cooler efficiencies of 50 watts of power input per watt of cooling at 65 kelvins for high-capacity systems (1 to 5 watts), making sorption coolers competitive with mechanical coolers. For low-capacity refrigerators (0.25 to 5 watts), the efficiency of these coolers is not as great, but they have the advantage of weighing less than equivalent mechanical units.

Accelerated reliability tests reveal an equivalent life in excess of 10 years for critical elements of these advanced cooler systems. One compressor, for example, has accumulated more than 13,000 hours of continuous operation without degradation.

Advanced Photovoltaic Solar Array

JPL has fabricated a prototype for the light-weight Advanced Photovoltaic Solar Array. Flight versions of this promising array are expected to quadruple the power/mass performance ratio of existing solar arrays, promising a significant increase in power but without a corresponding rise in mass — an important benefit for deep space or high-power (5- to 30-kilowatt) spacecraft.

The solar wing of the prototype array, measuring approximately three meters by three meters, employs weight-saving components and materials such as thin silicon solar cells, Kapton polyamide substrates and composite structural elements. In ground tests, the wing's deployment mechanisms have operated properly. The wing's mechanical integrity will be checked in subsequent tests that will simulate the vibrational and acoustic environment of a launch.

High-Power Lead-Acid Batteries

The Laboratory is researching a novel lead-acid battery design for use in high-power space applications. The battery — a combination of lead and lead-dioxide active materials found in automobile batteries — can generate 2 to 10 times more peak power than conventional units, with minimum volume and weight. This bipolar battery uses a single current collector for both positive and negative plates of adjacent cells. A specific peak power of 2.5 kilowatts per kilogram is expected for 30-second periods with as many as 2,000 recharge cycles.

The bipolar lead-acid couple has high open-circuit voltage, low electrolyte resistivity, very low cell-to-cell resistance and discharge, with an increase in entropy, making it ideal for high-power applications.

In 1990, three 50-kilowatt modules of a modified version of JPL's bipolar battery were built, and one was delivered to the U.S. Air Force for testing.

Carbon-Carbon and Composite Demonstration Technology

To reduce the failure rate of rocket engine exhaust nozzles, JPL has developed and demonstrated a reliable and reproducible carbon-carbon manufacturing process. This research has identified surface activity as a key parameter in manufacturing carbon-fiber structures and, moreover, has shown that such activity is determined by the orientation of the crystalline structure within each fiber.

A filament-wound rocket nozzle — the first prototype component made from the JPL process — survived test firing. The success of this test has led to carbon-carbon fabrication of larger nozzles as well as the fabrication of mirrors, optical benches and other components.

Spaceborne Image Processing

In recent years, the data-gathering capacity of sophisticated spaceborne instruments has outpaced the capabilities of transmitters to send that information back to Earth. JPL is now exploring ways to reduce the volume of transmitted data without compromising the value of the scientific information.

JPL has developed and demonstrated two computer chips capable of compressing data without losing information. The amount of loss-free compression depends on the complexity of the data; data compression ratios range from 2:1 for Earth observations to 3.5:1 for astronomical observations. The chips, operating successfully at speeds up to three times the design goal of 60 million bits per second, are candidates for use on the Earth Observing System's High-Resolution Imaging Spectrometer, the CRAF/Cassini Imaging Subsystem and the Space Infrared Telescope Facility.

Fiber-Optic Rotation Sensor

Research and development on advanced spacecraft control components have produced an all-solid-state inertial rotation sensor for space navigation. The Fiber-Optic Rotation Sensor uses photonics and fiber-optic technology to resolve small rotation rates (less than 0.01 degree per hour).

At the heart of the sensor is a single integrated-circuit chip incorporating all optical components, thereby guaranteeing stable alignment. This JPL-patented optical circuit reduces the impact of drift and non-linearity on the sensor's performance. In addition, the absence of moving parts is expected to extend the sensor's operating life to three or four times that of current mechanical gyros.

A brassboard of the Fiber-Optic Rotation Sensor is being tested by JPL and the Charles Stark Draper Laboratory.

Drop Physics Module

An understanding of how weightlessness affects humans must first begin with the study of the effects of microgravity on liquids and solids. As part of NASA's space laboratory program, a microgravity laboratory is being developed to study various materials in a very weak gravitational environment.

JPL's Drop Physics Module will be one of the facilities aboard the microgravity laboratory. The module has been designed to carry out experiments using weak acoustic fields, instead of walls, to position and manipulate drops of liquid with minimum distortion. The behavior of the liquid drop samples will be evaluated as stationary, rotated or deformed; the experimental data will be recorded on 16-millimeter film for postflight analysis. During the flight, data will also be videotaped and downlinked to the principal investigators, who will analyze the experimental results in near-real time. The module, now in the final phases of fabrication, will be delivered to the Kennedy Space Center in 1991 and launched aboard a space shuttle in 1992.

Energy Technology

For the Department of Energy, JPL applies its technology to the problems of energy conservation, pollution control and reduction of the nation's dependence on oil.

During the year, the Laboratory developed a new and potentially lower cost oxygen generation system using a zirconic solid electrolyte membrane to electrochemically separate oxygen from air. Several units, each generating one liter of oxygen per minute, were constructed and tested.

THE CENTER FOR SPACE MICROELECTRONICS TECHNOLOGY

The Center for Space Microelectronics Technology, established at the Laboratory in 1987, conducts research and advanced development in microelectronics to support new space missions for NASA and the DOD. Specifically, the Center develops and evaluates new electronic and optical concepts for improved sensors, real-time signal processing and high-data-rate information processing and storage.

The Center also explores novel concepts in advanced solid-state devices for potential space applications and develops the technological base for advanced space computing concepts and architectures. This year, progress was made in several areas: solid-state devices, photonics, custom microcircuits and advanced computing.

Advanced Sensors

Using electron beam lithography, the Center fabricated a superconducting tunnel junction mixer, achieving a record sensitivity in a 205-GHz receiver. These submicron-size mixers are being used in receivers at the Table Mountain Observatory in California and the Caltech Submillimeter Observatory in Hawaii to study star formations and other astrophysical phenomena.

During 1990, the Center invented and demonstrated a new silicon-germanium-silicon heterojunction infrared detector.

The new detector has an impressive photo-response range out to 17-micron wavelengths, and because it is made of silicon, the detector holds significant promise for large, inexpensive arrays required by both NASA and the DOD.

A novel accelerometer the size of a penny was also developed at the Center. Micro-machined from a silicon wafer, the device is 100,000 times smaller than an accelerometer with comparable sensitivity. Its exceptional sensitivity — detecting accelerations at the nanogram level, 10,000 times better than anything its size — is an outgrowth of earlier work on the electron tunneling sensor, another device invented at the Center. The accelerometer has many potential uses — as a seismometer for Earth and planetary geology or as an active-control sensor on large antennas or on other space structures.

High-Temperature Superconducting Microwave Devices

High-temperature superconductor development is an outgrowth of the Laboratory's expertise in conventional supercomputing technology, thin-film deposition and device fabrication. One of the first uses of the recently discovered high-temperature superconductors may be in passive, low-loss microwave circuits for space applications.

Compared with normal metals, these new materials offer lower electrical losses at microwave frequencies. In addition, these materials can be cooled with liquid nitrogen instead of the more expensive and cumbersome liquid helium.

JPL has successfully fabricated microwave filters made of high-temperature superconductors, which have been delivered to the Naval Research Laboratory. The units may be tested aboard a satellite, scheduled for launch in 1992 and expected to be the first test and demonstration of high-temperature superconducting devices in space.

Acousto-Optic Tunable Filter Imaging Spectrometer

A new generation of imaging spectrometers for future space exploration missions is being developed at the Laboratory. The spectrometer uses an acousto-optic tunable filter. This type of spectral bandpass filter has a number of attractive features for use as a wavelength sorter for spaceborne imaging spectrometry: It can be electronically tuned over a wide wavelength range in microseconds, can provide high resolution and can operate in sequential, random and multi-wavelength access modes. These filters are also all solid-state, compact, rugged and lightweight. When these robust, flexible, programmable bandpass filters are placed in front of a camera, they form an imaging spectrometer that can take monochrome images of a scene at desired wavelengths in a selected sequence.

During the year, JPL successfully developed a microcomputer-controlled imaging spectrometer using a tellurium dioxide acousto-optic tunable filter. The breadboard system operated in a wavelength range of 500–800 nanometers with a spectral resolution of 4 nanometers.

Fiber-Optic Experiment in Space

The recovery of the Long Duration Exposure Facility, which spent five and a half years in space, gave scientists a unique opportunity to observe the effects of space on fiber optics. JPL's experiment carried 10 samples of various types of fiber-optic cables. Four samples, each 25 meters (82 feet) long, were mounted externally, and six samples, 50 meters (164 feet) long, were carried inside on a tray. Each sample was fitted with commercial fiber-optic connectors.

The initial assessment of the 10 samples revealed no serious problems. However, subsequent examinations showed evidence of radiation-induced transmission loss, micrometeoroid impacts, contamination of some connector terminals and superficial fading of jacketing materials. Despite the lengthy orbit, 3 of the 10 samples showed no measurable increase in loss. The other samples were functional but showed some loss, possibly due to radiation darkening. Overall, JPL experimenters believe that properly designed fiber-optic cables can be used in space.

Electronic Neural Networks

The concept of neural networks was inspired by the human brain's method of processing information. Similar to the billions of neuron cells in the brain that communicate among themselves through trillions of interconnected synapses, neural networks use many individual processors (neurons) that can simultaneously communicate with each other through links (synapses). These neural networks have a range of potential applications — robotic control, planetary rover path planning, multitarget tracking, resource allocation and multispectral data classification.

During 1990, a reconfigurable neural network developed by JPL demonstrated its "brainlike" ability to solve the kinds of complex problems usually solved by robots. From only a limited set of examples, the JPL neural network carried out mapping tasks at speeds orders of magnitude faster than digital circuits. After reconfiguration, the same network learned to recognize satellite images of ground features such as vegetation, lakes and urbanized areas.

The high-speed performance demonstrated by JPL's neural network hardware is paving the way for the development of neuro-processor prototypes for a number of NASA and DOD applications, such as cartographic analysis or route mission planning. This technology, developed for the U.S. Government, is already being transferred to industry for other defense and commercial applications.

Concurrent Computing

In the 1980s, Caltech and JPL played a major role in parallel computation with the development of the Hypercube concurrent computer. The Hypercube, invented at Caltech and refined by JPL, allows scientific and engineering data processing at supercomputing speeds. By 1990, the system had been successfully transferred to industry, with more than 400 Hypercube systems sold worldwide.

Since the development of the Hypercube, its supercomputing power has been applied to a number of JPL projects such as the processing of images received from the Voyager 2 spacecraft during its encounter with Neptune in 1989. Using the powerful computing capabilities of the eight-node Mark IIIfp version, the Laboratory's Image Analysis Systems team was able to create mosaic images and rotational movies of the planet and its major moon, Triton, in near-real time.

The Mark IIIfp Hypercubes are also being used to study solar and space plasma physics. Plasma particles are simulated through one- and two-dimensional codes. In these simulations, the orbits of thousands to millions of plasma electrons and ions are computed as the particles move in an electromagnetic field calculated self-consistently from the particles.

Anticipating an unprecedented amount of data generated by future NASA space missions, JPL is presently developing a parallel processing environment that will enable scientists to handle large-scale atmospheric profiles of temperatures, pressures and chemical constituents.

In 1990, a consortium of 14 research institutions was formed to procure and utilize the Intel Delta parallel computer. The Delta — based on technology developed at Caltech — will have 528 nodes with a peak performance of 32 gigaflops, making it the world's most powerful computer. When it is installed at Caltech in 1991, the Delta will be used by the Information Processing Center to analyze large, intensive computational problems in spacecraft systems design, space science and space-data visualization and analysis.

Time Warp

The Time Warp Project, conducted by JPL and the University of California at Los Angeles, is developing a new class of operating systems for parallel processors similar to the Hypercube. The operating systems allow discrete event, object-oriented simulations such as mission operations or war games to be executed asynchronously on parallel processors. Research this year focused on the process of dynamic load management so that the processor tasks could be shifted from one processor node to another to relieve local overloading.

Supercomputing Project

During 1990, the JPL CRAY X-MP/18 supercomputer completed its first year of operation. Caltech and JPL scientists and engineers have used the CRAY to tackle such problems as the design of Deep Space Network antennas and the modeling of astrophysical jets and planetary atmospheres. This work has been reported in several dozen scientific and technical journals.

SPACE AUTOMATION AND ROBOTICS PROGRAM

Space Robotics

JPL's goal in Space Robotics is to provide the technology for an operator on Earth to carry out physical manipulations at remote sites, such as other planets.

During the year, JPL began a laboratory duplication of the tasks astronauts performed in 1984 when they repaired the malfunctioning Solar MAX spacecraft in orbit. A partial mockup of the Solar MAX spacecraft helped identify subtasks which could be done with today's robotic capabilities. This work will continue until Space Robotics completes the entire Solar MAX repair task.

In a demonstration of supervised autonomy, a robot executed a novel simulated exchange of a Space Station connector. Computers planned the exchange, defined the robot's motions in accordance with the plans and then modified the plans when an obstacle was encountered. They controlled the robot's motions including management of forces when the robot contacted another object. The human operator only provided "high level" commands, telling the robot what and where to move and identifying and defining the location of the unknown object.

The robot also performed a simulated exchange of a Space Station orbital replacement unit, despite an error deliberately inserted in the data base. Encountering the error, the robot notified the operator, who coached it into correcting its data base. The robot then completed its task.

Also last year, JPL and NASA Kennedy Space Center (KSC) demonstrated the feasibility of operating robotic systems remotely. In a

program called "Telerobotic Control From 3000 Miles," JPL operators in Pasadena used a large robot at KSC to examine a mockup of a Space Shuttle cargo bay. They determined the robot's location in its environment from pictures sent over phone lines and analyzed with machine vision technology. Computers formulated control commands routed to KSC for execution by the robotic system.

In still another exercise, JPL built and transferred copies of its unusual "force-reflecting hand-controller" and software technology to NASA Goddard Space Flight Center. This system allows the operator to "feel" on his own hand the forces at the robotic end-effector as he performs tasks on objects in the remote environment. With the system, Goddard engineers can analyze the amount of force feedback, assessing the "crispness" of the feel required by the Flight Telerobotic Servicer to execute Space Station tasks.

The initial Telerobotics/EVA Joint Analysis Software (TEJAS) tool was released this year. TEJAS allows quick, easy access to, and extraction of, robotic definitions and background information. Task scripts can be developed from TEJAS for both astronaut extravehicular activity and telerobots.

JPL's advanced technology in Space Robotics is creating technological expertise needed for future scientific exploration of the Solar System. Simultaneously, its relevant technological advances are funneled into other NASA projects.

Rover Technologies

In September, JPL's rover navigation testbed "Robby" recorded landmark success. The six-wheeled, three-body, articulated vehicle demonstrated sufficient intelligence to traverse 100 meters of rugged, natural terrain without human guidance. This was the first time a robotic vehicle negotiated its own path in a planet-like environment. Robby's stereo-derived, passive ranging enabled it to perceive the terrain in three dimensions. Without human intervention, its computers planned a safe path to a goal obscured by bushes and rock 100 meters away. The demonstration is applicable to Martian surface exploration, where lengthy round-trip transmission times make it impractical for controllers on Earth to remotely drive a robotic rover.

In separate experiments, Laboratory specialists developed ways of controlling autonomous coring of hard igneous rocks, typical of planetary or lunar surfaces. An autonomous hierarchical classifier, based on neural networks, is designed to process multispectral landscape images viewed by the autonomous rover and to interpret their geology and composition.

Knowledge Systems

The Knowledge Systems activity helps manage the Laboratory's growing number of artificial intelligence (AI) ventures and promotes research, development and application in this field. Such systems will play a

major role in automating mission operations, managing science data and analytical tools and achieving greater autonomy in the next generation of spacecraft.

In 1989, the JPL-developed Spacecraft Health Automated Reasoning Prototype (SHARP) was used by Voyager telecommunications analysts during the Neptune encounter. The system demonstrated effective automation of real-time monitoring and diagnostic functions for spacecraft subsystem analysts. It significantly benefitted productivity, spacecraft safety and reliability.

This year, the Laboratory adapted SHARP for Magellan's telecommunications analysts at the Space Flight Operations Center. In coming years, it will investigate automation of link monitoring and control functions in the Deep Space Network.

Research is under way on designs for AI-based monitoring systems to maximize the feedback of critical engineering information from complex, dynamic space systems to human operators. The intent is to avoid overloading both human and computational resources as they interpret sensor data.

JPL's development of AI-based software has potential uses in planetary spacecraft scheduling, Space Station Freedom and the Deep Space Network. The Operations Mission Planner System has automatically generated acceptable schedules for up to one thousand tasks in an eight-hour day in only a few minutes of computer time. It can re-plan schedules dynamically in real-time, simultaneously avoiding disruption of already scheduled activities.

Through the Applications Projects, JPL fulfills its obligation as a major national laboratory by working on significant national problems. Projects are selected in areas where the Laboratory's special capabilities can make important contributions. Sponsors include the Department of Defense (DOD), the Department of Energy (DOE) and the Federal Aviation Administration (FAA). Through the Technology Affiliates Program, JPL also assists businesses in developing engineering and science technology for commercial use.

During 1990, the Laboratory made notable progress in Applications Projects and in technology spin-offs. Several JPL prototype systems also achieved key milestones toward initial application. And the Laboratory was pleased to initiate two new projects that were based on previous JPL research and technology.

ASAS PROJECT

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The All-Source Analysis System (ASAS), currently being developed by JPL and its subcontractors, is a mobile data-processing system that collects, integrates and analyzes tactical battlefield information. Since the U.S. Air Force — the original ASAS cosponsor — withdrew from the effort, the focus of the project has shifted to satisfying Army requirements.

The ASAS team, led by JPL, is now producing a new version of ASAS software. Consisting of nearly 1.5 million lines of code, the new software will provide the system with the full capability required by the Army.

JPL designed and delivered new ASAS hardware equipped with the first software version to Fort Hood, Texas, for Army testing and evaluation. Once the acceptance tests were completed, this initial version of ASAS, in a limited capabilities configuration, became the first mobile system to be fully security-accredited by the Army. Additional hardware equipped with the new software will be assembled, integrated and tested at Fort Hood in 1991. At the same time, more hardware modules and workstations will be produced for deployment in Europe. ASAS deliveries to the Army are expected to be completed by the end of 1994.

SP-100 PROJECT

The Space Power-100 Project (SP-100), a program to develop a nuclear-based electric power system for space missions, made a major breakthrough this year with the successful production of thermoelectric material, a gallium phosphide-doped silicon-germanium alloy. This material demonstrates a 20-percent improvement in performance over the thermocouple material used in the Galileo spacecraft's Radioisotope Thermoelectric Generators. JPL manages the project, which is jointly sponsored by the DOE, DOD and NASA.

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During the year, the project assembled a mock-up of a hydraulic reactor flow test, which is used to characterize reactor core flow and pressure distribution. The project also fabricated half of the fuel pellets needed for the reactor tests and completed development of the fuel-pin cladding.

The SP-100 system could be used for future deep space missions and a lunar base. Researchers believe the system could provide all the power a lunar outpost would require for more than seven years.

ANALYSIS AND TRAINING SYSTEMS PROJECT

JPL made important improvements this year to a computer-based simulation system used in Army training exercises. Previously called the Joint Exercise Support System, the training system is now known as the Corps Battle Simulation (CBS) system. The CBS system allows corps, division and brigade commanders and staffs to exercise wartime duties in simulated battle drills. The system has been installed in more than a dozen Army, Air Force and Joint battle simulation centers, where it is being used for approximately 30 exercises annually. In 1991, the British Ministry of Defense plans to install a CBS system in a British battle simulation center.

During the year, a combat attrition mechanism, developed by JPL, was introduced into the CBS system. The mechanism enables military personnel to evaluate selected combat situations and to modify applicable combat attrition equations in real time. This new simulation technique should greatly enhance the realism of simulations.

Other enhancements being planned include linking multiple CBS systems to each other and to other Army simulation systems. This enhancement could increase the number of participants and expand the range of exercise possibilities.

REAL-TIME WEATHER PROCESSOR PROJECT

The Real-Time Weather Processor Project has designed a weather processor that can collect, integrate and distribute weather information to air traffic controllers in real time. The project is sponsored by the FAA as part of an ambitious National Airspace System Plan for upgrading the nation's airways. JPL serves as systems manager for the project.

Coding and unit testing for the system were completed early in 1990. After system integration and testing were concluded in May, the FAA conducted formal system acceptance tests against 209 specified requirements. The system met 90 percent of these requirements immediately and most of the others by the end of the year.

In June, approximately 25 weather processor operators and meteorologists from various FAA Area Control Centers participated in a training program at JPL. Following training, they participated in the operational testing and evaluation of a prototype processor so that, as future users, they could make recommendations on the system's functional capabilities and performance. The FAA and JPL are jointly evaluating their suggestions for possible implementation.

During 1991, JPL plans to incorporate a number of enhancements into the Weather Processor System. One such enhancement is a radar interconnect system that will collect weather data from as many as 16 radars located at one FAA Area Control Center and then will transmit the data to adjacent Area Control Centers in real time. This system will be able to link weather radars located over nearly 10 percent of the continental United States. JPL is also working on improvements in the system's graphic displays and human-machine interfaces.

Software developed by JPL using off-the-shelf hardware will be used in the operational radar weather systems installed in 23 FAA Area Control Centers.

VOICE SWITCHING AND CONTROL SYSTEMS

JPL supplied a Traffic Simulation Unit to the FAA in January 1990 for testing two Voice Switching and Control System prototypes, both built by industrial contractors under the National Airspace System Plan. Both contractors and the FAA have found the unit to be an effective tool for testing the functional capability and performance of the two prototypes.

COMMAND AND CONTROL AUTOMATION PROJECT

The Command and Control Automation Project resumed in October 1989, after a year's hiatus following successful development of command centers for the Military Airlift Command. The project is developing the command center system for the U.S. Transportation Command. The Transportation Command will use the system to monitor and control air, land and sea transportation assets. During the year, JPL developed an interim command center system, which was subsequently installed at the Transportation Command and used during the Persian Gulf crisis.

EUCOM COMMAND CENTER PROJECT

The European Command (EUCOM) Command Center Project will provide the U.S. European Command Headquarters with a state-of-the-art command center system. The system will permit the commander and his staff to efficiently perform command and control functions. JPL is systems integrator and supplier of selected subsystems.

The U.S. European Command, located in Stuttgart, Germany, directs the activities of U.S. military personnel in an area three times larger than the continental United States. The project's objectives are to integrate EUCOM's many separate command support systems into a unified operational system and to develop and integrate new

systems. The first equipment, including a computerized management briefing system and local area networks, was delivered in October and underwent more rigorous testing than anticipated during EUCOM's participation in Operation Desert Shield.

The EUCOM Command Center Project is part of a broader Command Center Improvement Program authorized by the Joint Chiefs of Staff and conducted by the Army at Fort Monmouth, New Jersey.

TECHNOLOGY COMMERCIALIZATION

The goal of JPL's Technology Affiliates Program is to transfer the Laboratory's technology to industry, thereby strengthening U.S. industry's competitive positions in the international market. During 1990, JPL assisted Diatek, a San Diego medical equipment company, in refining an innovative thermometer design targeted for a \$45-million market. This hand-held tympanic thermometer is positioned in a patient's ear canal to measure body temperature.

Technical difficulties in Diatek's design concept were resolved by JPL engineers, who applied optical design techniques that were originally developed for infrared remote-sensing spacecraft. JPL's contribution proved invaluable when clinical testing verified the thermometer's successful performance.

Diatek is one of 32 companies to participate in the Technology Affiliates Program. The Diatek experience, highlighted in the JPL exhibit at NASA's Technology 2000 Conference, is just one example of JPL's successful technology commercialization work with industry.

Research and development costs for the fiscal year ending September 30 were \$1.050 billion, a 1.2-percent decrease from the previous year.

Costs for NASA-funded activities rose 4.6 percent to \$778 million. Costs for non-NASA activities totaled \$272 million, a decline of 15 percent.

The work force increased during the year to 6,114, compared with 5,892 in 1989 and 5,736 in 1988.

Procurement obligations during the fiscal year totaled \$673 million, a 4-percent increase over 1989. These outlays included \$632 million to business firms, of which \$129 million went to small businesses and \$30 million to minority-owned businesses.

NASA HONOR AWARDS

The NASA honor awards, presented annually by NASA, recognize outstanding achievements by individuals and teams. Nominations are made by JPL. The following awards were presented in a ceremony at the Laboratory on September 21.

Distinguished Service Medal

- Lew Allen
- W. E. Giberson

Outstanding Leadership Medal

- Terrence P. Adamski
- Raymond J. Amorose
- J. Pieter deVries
- Peter E. Doms
- John H. Gerpheide
- Donald L. Gray
- Norman R. Haynes
- Howard P. Marderness
- Lanny J. Miller
- Ellis D. Miner
- Richard P. Rudd
- Gary L. Spradlin

Exceptional Scientific Achievement Medal

- John W. Belcher
- Barney J. Conrath
- Daniel D. Elleman
- Donald A. Gurnett
- W. Timothy Liu

Exceptional Engineering Achievement Medal

- Donald W. Brown
- Donald H. McClure
- Ronald G. Ross, Jr.

Equal Employment Opportunity Medal

- Peter T. Lyman

Public Service Medal

- Charles T. Boreham
- William D. Brundage
- Henry E. Harper
- Mark L. Molander
- Judith A. Morris
- Rex W. Ridenoure
- Edward F. Wahl

Exceptional Service Medal

- David J. Atkinson
- Susan E. Borutzki
- Noel H. Burden
- Earl R. Collins
- Henry Cox
- Marie-Jose C. Deutsch
- Suzanne R. Dodd
- Albert J. Fender
- Thomas J. Fouser
- Justin R. Hall
- Candice J. Hansen
- John C. Hardy
- John W. Harrell
- Douglas S. Hess
- Linda J. Horn
- Steven M. Howard
- Robert A. Jacobson
- Mark L. James
- Paul Jepsen
- Donald R. Johnson
- Satish K. Khanna
- Adans Y. Ko
- Emil R. Kursinski
- David B. Lame
- Meemong Lee
- Henry N. Levy, Jr.
- Patricia K. Liggett
- Susan H. Linick
- Michael D. Martin
- Paul F. McCaul
- Richard B. Miller
- Lawrence C. Montgomery
- Roy M. Otamura
- John L. Ovnick, Jr.
- William M. Owen, Jr.
- Robert G. Petrie
- Robert L. Poynter
- James D. Quinn
- Joseph E. Riedel
- Kenneth Savary
- John Schlue
- James S. Shell

- Norri Sirri
- Joel G. Smith
- Robert E. Sutherland
- Jack M. Tallon
- Gerard A. Tembrock
- Anilkumar P. Thakoor
- Reid C. Thomas
- Kathryn R. Weld
- Randii R. Wessen
- Albert C. Whittlesey
- William R. Woods

MINORITY SCIENCE AND ENGINEERING INITIATIVES

During 1990, the Jet Propulsion Laboratory established a broad-based Minority Science and Engineering Initiatives Office in the University Affairs Office. This program is responsible for a range of minority initiatives at JPL that promotes science and engineering careers among underrepresented minorities and encourages collaborative research with selected colleges and universities.

The Memoranda of Understanding between Caltech-JPL and three Historically Black Colleges and Universities (HBCUs) have been signed. These memoranda establish a long-term joint program to advance the development of human potential through collaborative efforts. The three HBCUs include Jackson State University, Tuskegee University and Clark Atlanta University.

The Initiatives

Hispanic Initiative. Under this initiative's agreement, JPL will provide summer fellowships and employment for University of Texas at El Paso (UTEP) faculty; will grant UTEP personnel loans of JPL staff whose assignments will range from guest lecturer to

two-year teaching and research posts and will loan equipment, when appropriate and available, for UTEP research efforts. The initiative also will give UTEP students an opportunity to participate in summer internships and employment activities at JPL.

Native American Initiative. In 1989, JPL and Northern Arizona University created the Sacred Mountain Scholars program. This program supports 20 Native American students, from the Navajo, Hopi, White Mountain and Yavapai Apache tribes, who are majoring in science or engineering. The Sacred Mountain Scholars program is funded by NASA under a training grant and provides each student with summer research and technical work at the Laboratory.

Historically Black Colleges and Universities Initiative. This initiative, now in its second year of operation, made several gains in 1990. In an effort to increase university participation in the HBCU Initiative, the Minority Science and Engineering Initiatives Office began preparation for its Third Annual Technical Workshop to be held in January 1991. This workshop will be the largest ever, with an anticipated attendance of 150 science and research faculty members, college presidents and vice presidents from HBCUs and representatives from Federal agencies associated with minority university programs. The three-day conference will focus on minority recruitment in Earth and physical sciences and engineering.

Research and Development Initiative. The Research and Development Initiative is designed to increase the participation of HBCUs and their principal investigators in aeronautics and space research. This year JPL supported research and student activities at the following universities:

- Clark Atlanta (a new type of artificial intelligence; data base administrative training)
- Central State (robotics)
- Jackson State (testing and operation of space instrumentation)
- North Carolina A&T State (channel coding)

EDUCATIONAL OUTREACH

In its program dubbed CATS, for Comfortable Approach to Teaching Science, JPL is helping teachers with little scientific background to teach science with confidence. CATS is a joint venture involving NASA, JPL and the California State Polytechnic University at Pomona. This project, in its third year of operation, involves four weeks of intensive instruction during the summer, with a follow-up program the following school year. The program is being extended to include several HBCUs and Native American institutions.

In partnership with the Pasadena City College and Caltech, JPL supports the "Space Academy," one of several "partnership" academies developed by the Pasadena Unified School District. The Space Academy curriculum provides students with applied science and engineering training, plus pro-

fessional mentors, paid internships and college course work — with the express purpose of encouraging minority youngsters to enter science and engineering careers.

DISTINGUISHED VISITING SCIENTIST PROGRAM

The Distinguished Visiting Scientist Program was established at JPL to promote an interchange between researchers worldwide and our own Caltech and JPL scientists and engineers. The purpose of the program is to strengthen and advance areas of research that are of particular interest to JPL by providing a forum for the exchange of ideas, research methods and technical expertise.

The following scientists, who were appointed in 1990, have spent 2 to 12 months at JPL, offering their insights and expertise in the indicated fields.

Multispectral Reflection Spectroscopy

Jeff Dozier
University of California
Santa Barbara, California

Computer Science and Engineering

Aaron Finerman
Computing Center
Michigan

Geodynamics

Bradford H. Hager
Massachusetts Institute of Technology
Cambridge, Massachusetts

Solar Astronomy and Solar Spectra

John T. Jefferies
National Optical Astronomy Observatories/
National Solar Observatories
Arizona

Radar Science and Engineering

Merrill Skolnik
Naval Research Laboratory
Washington, D.C.

SENIOR RESEARCH SCIENTIST OR ENGINEER

The position of Senior Research Scientist or Engineer is awarded to those scientists or engineers who have shown outstanding achievement and leadership in their fields. Researchers serve in this capacity for at least one and one-half to two years. The outstanding researchers listed below earned their appointment during 1990.

Atom and Ion Scattering

Ara Chutjian

Geophysics and Infrared Remote Sensing

Anne B. Kahle

Laser Spectroscopy and Atmospheric Chemistry

Christopher R. Webster

PATENTS AND TECHNOLOGY UTILIZATION

During fiscal year 1990, the Office of Patents and Technology Utilization prepared, evaluated and forwarded to NASA reports on 265 inventions and technical innovations resulting from JPL work. The office answered 62,823 requests from industry and the public for technical information on JPL inventions and innovations published in the NASA-sponsored monthly *Tech Briefs*. During the year, 260 *Tech Briefs* from JPL were published, 41 percent of the NASA-wide total. The U.S. Patent Office issued 56 patents to Caltech and NASA on inventions made at JPL.

During the year, NASA granted the following exceptional and major monetary awards for inventions made at JPL.

Exceptional Awards

Marshall F. Humphrey, Kenneth R. French and Ronald D. Howe shared \$5,000 for "Ozonization of Cooling Tower Waters." Humphrey received \$3,000; French and Howe each received \$1,000.

William J. Kaiser and L. Douglas Bell shared \$10,000 equally for "Tunnel and Field Effect Carrier Ballistics."

Chaitan Khosla and James E. Bailey shared \$6,000 equally for "Enhancement of Cell Growth by Expression of Cloned Hemoglobin Gene and Oxygen Related Control of DNA Sequence Transcription and Translation."

Major Awards

John C. Peterson, Edward Chow and Herb S. Madan shared \$3,000 equally for "Method and Apparatus for Eliminating Unsuccessful Tries in a Search Tree."

Kenneth R. Castleman received \$2,000 for "Automated Quantitative Muscle Analysis System."

J. Brooks Thomas received \$1,000 for "Digital Signal Processor and Processing Method for GPS Receivers."

Wally E. Rippel received \$1,000 for "Forced Air Heat Sink Apparatus."

Charles A. Greenhall received \$1,000 for "Apparatus for Using a Time Interval Counter to Measure Frequency Stability."

William J. Kaiser and Steven B. Waltman shared \$2,000 equally for "Tunnel Effect Measuring Systems and Particle Detectors."

Norman A. Page and Mary L. White shared \$2,000 equally for "A Compact Fast Wide Angle Broadband Spectrometer Optical System."

Another 479 employees received minimum (\$250-\$500), nominal (\$250-\$999) and *Tech Brief* (\$150) awards totaling \$111,950.

DIRECTOR'S DISCRETIONARY FUND

The Director's Discretionary Fund (DDF) is the major resource to support innovative and seed efforts that cannot receive conventional task-order funding. For 1990, the DDF increased to \$3.5 million a year.

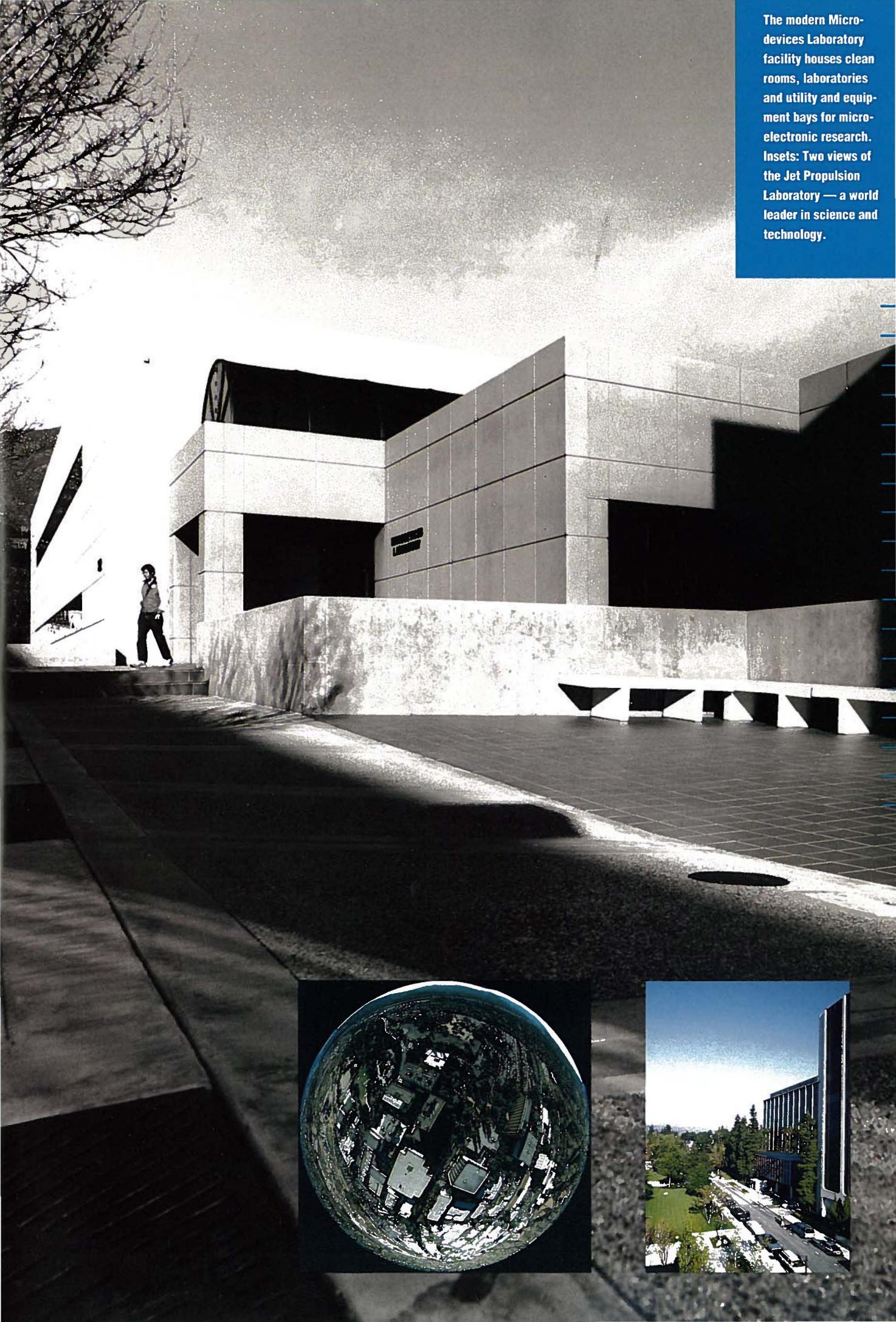
This year, the fund initiated 27 new research tasks, extended the objectives of 7 ongoing tasks — awarding more funds to them — and provided modest assistance to several other support efforts. Proposals that are eligible for DDF funds cover a broad range of sciences and technologies. Areas of recent emphasis include advanced microelectronics, automation and robotics, advanced observational techniques and technology for advanced optical systems.

The DDF recognizes important mutual benefits from collaboration with faculty and students at Caltech and other academic institutions, so cooperation is specifically encouraged. Eleven new and extended principal tasks funded this year involve university faculty collaborators.

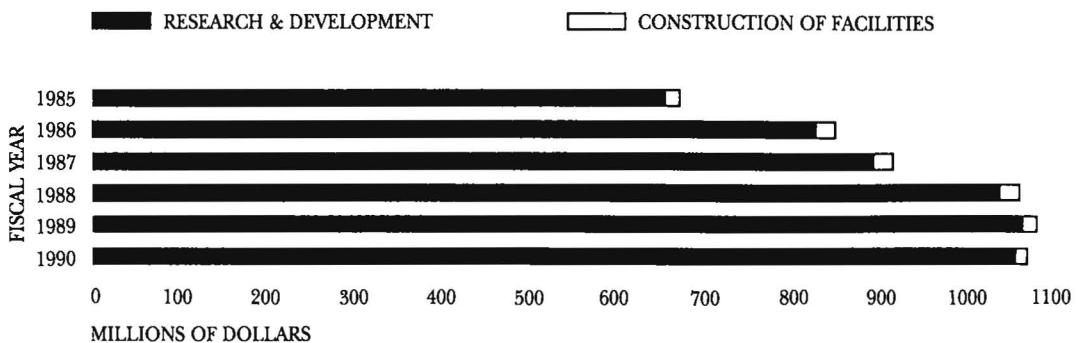
PRESIDENT'S FUND

The Caltech President's Fund provides a second, although smaller, source of discretionary funding. Currently at a level of \$1 million a year, the fund comes from Caltech and NASA resources on a dollar-for-dollar matching basis and is administered by Caltech. An explicit objective of the President's Fund is to encourage the interest and participation of university faculty and students in JPL research activities to afford JPL staff members an opportunity for close association with research workers from the university community. The President's Fund provided resources for 15 new collaborative tasks this year.

The modern Micro-devices Laboratory facility houses clean rooms, laboratories and utility and equipment bays for micro-electronic research. Insets: Two views of the Jet Propulsion Laboratory — a world leader in science and technology.

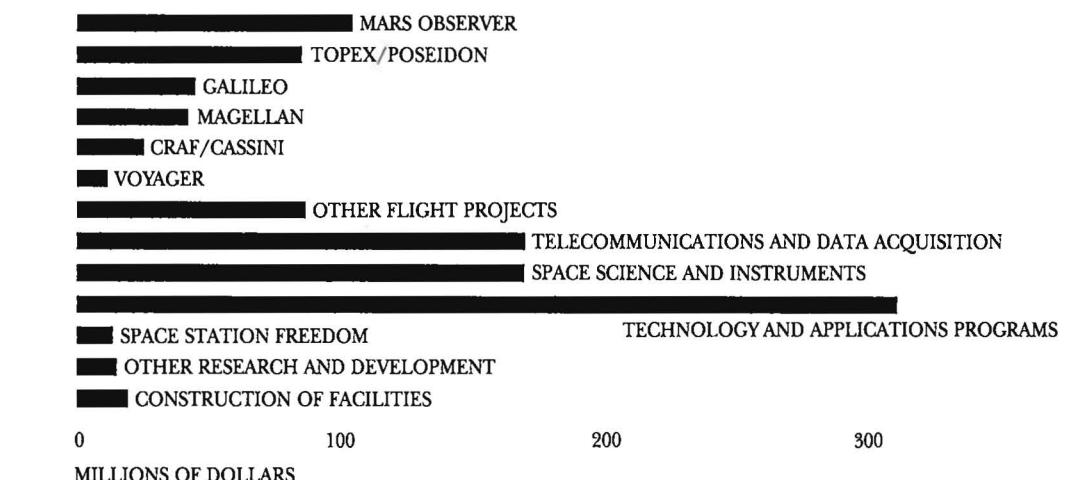


TOTAL COSTS

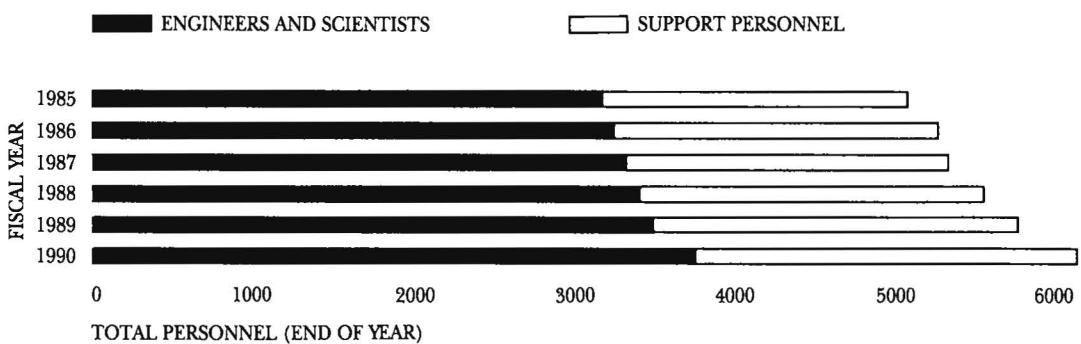


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FISCAL 1990 COSTS



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